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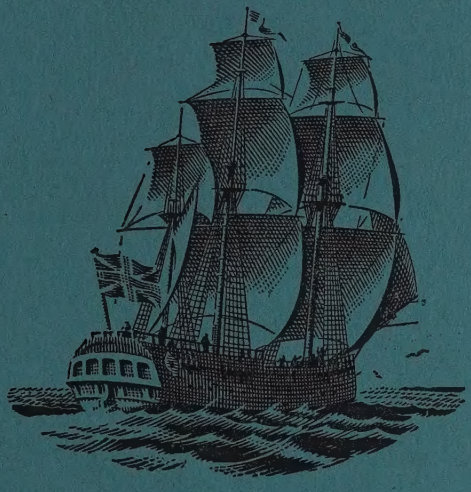

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The drawing on the cover is of the bark Endeavour, *which, commanded by Captain James Cook and carrying a number of scientific workers, was sent out by the British Admiralty in* 1768 *to chart the South Pacific Ocean and observe the transit of Venus*

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A quarterly review designed to record the progress of the sciences in the service of mankind

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René Descartes (1596–1650)

The mutual influence of French and British thought and discovery in the development of modern science is a matter of history. Lavoisier's synthesis of chemical philosophy, founded partly on his own researches and partly on the experiments and discoveries of his contemporaries Black, Priestley, and Cavendish, is perhaps the most notable example. The present year, marking the tercentenary of the death of Descartes, recalls not only one of the inaugurators of modern science, but one who much admired his British contemporaries and greatly influenced their successors.

The principal works of Descartes are *Le Discours de la Méthode* (1637), containing his *Géométrie*, which marked the foundation of analytical or co-ordinate geometry; *Meditationes de Prima Philosophia* (1641); and *Principia Philosophiæ* (1644).

Descartes read and praised Bacon's *Novum Organum* (1620), but, unlike Bacon, considered that science would best advance by deduction rather than by induction, and by deduction only from what could be accepted as certain because it was indubitable—a view which is expressed in the well-known phrase, *Cogito, ergo sum*, but which might have been more exactly conveyed as *Dubito, ergo sum*. Also unlike Bacon, he realized the importance of mathematics in the furtherance of science; and once again unlike Bacon, he thought very highly of Gilbert's *De Magnete* (1600), and himself formulated the first scientific theory of magnetism. For Harvey's *De Motu Cordis* (1628) he had the greatest admiration.

His foundation of analytical geometry, his studies on motion, his work on refraction and the rainbow, his opposition to explanations that assumed occult qualities, his aim of basing all physical studies on mechanics, and his contention that animals were 'machines,' characterize him as one of the moderns. He was, indeed, one of the first 'mechanical' philosophers. He led science away from an Aristotelian world, and his system was replaced only by that of Newton.

Descartes considered that matter was continuous and that the world was a *plenum*, in contradiction to those who had begun to adopt a revived Greek atomism, and who argued that the world was composed of atoms and void. In his theory of vortices, the motion of a planet in its orbit was maintained by the vortex motion of a material filling all space.

These two ideas, a continuous but corpuscular matter filling all space, and a universe of vortices, were eagerly discussed among his successors in Britain. Walter Charleton, who described Descartes as 'a Wit transcendently acute,' reveals the influence of Cartesianism in his *Physiologia* (1654), the first English book on atomism, in writing that 'the opinion [on vision] of the excellent *Monsieur Des Cartes*, . . . with a kind of pleasant violence, hath so ravisht the assent of most of the Students of Physiology [i.e. Physics], in the præsent Age, especially such as affect the accommodation of Mechanick Maxims to the sensible operations of Nature, that their minds abhor the embraces of any other.'

Boyle had a great respect for Descartes, described him as 'ingenious' and 'excellent' and one 'from whom I am not forward to dissent,' and regarded Democritan atoms and Cartesian corpuscles as rivals, although he himself came to prefer the former. In his *Origin of Formes and Qualities* (1666), Boyle, partly under the influence of Descartes, gave full support to a corpuscular philosophy in explaining the properties of substances on purely mechanical grounds, and the ideas expressed in the book were well received.

Hooke, who was well acquainted with the writings of Descartes—whence, in Newton's opinion, he had derived his theory of colour—mentions Descartes several times in his *Micrographia*

(1665), and in his *Lampas* (1677) he wrote: 'Now though, I confess, I suppose Gravity to be otherwise performed than as Des Cartes has supposed, yet do I believe his Suppositions so Rational and Ingenious, and so much above the Objections brought against them, and so much better than any other I have yet met with, as no wise to deserve to be esteemed *fœda deliria*, as the learned Doctor [Henry More] is pleased to term them.' More was the Cambridge Platonist, who had called upon contemporary science to support Christianity against scepticism; later, in his *Enchiridion Metaphysicum* (1671), he renounced Cartesianism, which, with Cudworth and his fellow-Platonists, he had come to regard as mere atheism, although it was founded on a belief in the existence of God. More's criticism, after the publication of the *Origin of Formes*, had deeply disturbed Boyle, who had often emphasized the basis of Cartesianism, but a not altogether satisfactory explanation in a letter from More to Boyle, to the effect that he had written only against the materialistic aspects of the system, seems to have saved a possible breach between two friends.

Newton, it is known, read the *Géométrie* of Descartes in 1664 and devised his 'method of fluxions' in 1665; it has been held that the ideas he may have obtained from the *Géométrie* were possibly a factor in his invention of the calculus.

In his *Principia*, Newton had to deal with the vortex theory of Descartes, which, with increasing knowledge, had become accepted in place of the Aristotelian system of the world, and to its refutation he devoted most of Book II. In Proposition LII he showed that, in a vortex system, the periodic times of its different parts must be as the squares of their distances from the centre, whereas the observations summarized in Kepler's third law had shown that the squares of the periodic times of the planets were as the cubes of their distances from the Sun. However, even after the publication of the *Principia* in 1687, Cartesianism remained acceptable in many quarters, possibly because the vortex theory kept the planets rolling by contact with the ever-moving subtle fluid that filled all space, whereas Newton's system involved the incomprehensible 'action at a distance.'

The second edition of the *Principia* appeared in 1713, twenty-six years after the first. Roger Cotes, who wrote for it his well-known Preface, was still mainly concerned with the refutation of the vortex theory, the continued acceptance of which was due not only to the difficulty in Newton's system already mentioned, but to the popularity of a remarkable textbook of physics. This was the *Traité de Physique* of Jacques Rohault, which was founded on the system of Descartes and which first appeared in 1671. Latin translations were published in Geneva in 1674, and in London in 1682. Many French editions followed, and, before Newton's *Principia* appeared in 1687, the *Traité* had established itself in British universities. Later, it maintained its place even in Newton's own university of Cambridge, although the Newtonian system had been taught in Edinburgh by David Gregory before he left for Oxford in 1690, and in St. Andrews by his brother James. In Oxford, Cartesianism was still the 'New Philosophy' (as opposed to that of Aristotle) in 1693, when Addison defended it in an oration in the Sheldonian Theatre. When, however, another Latin version (1697) of Rohault's *Traité* was in course of preparation by Samuel Clarke, protests by Whiston led the translator to add notes on Newton's work to the later editions; these, in effect, contradicted the text, so that, in Playfair's words, 'the Newtonian Philosophy first entered the University of Cambridge under the protection of the Cartesian.' This new translation appeared in 1697, and later editions followed; there were also English versions in 1723, 1728–9, and 1735.

It was not until the middle of the eighteenth century that Cartesianism finally gave way to Newtonianism. Yet, while the cosmical system of Descartes was rejected, the influence of its inventor persisted in other directions throughout the eighteenth and nineteenth centuries. It persists, indeed, even now, through his belief in the existence of an objective material world, the mechanism of which it was the primary aim of science to unravel.

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What is an elementary particle?

E. SCHRÖDINGER

Increasing knowledge has in some ways made us not more certain but less certain of the nature of matter. Whereas Dalton and his school had a clear picture of the existence of atomic particles as real and indestructible solid particles, modern wave mechanics implies very clearly that, in fact, they are not identifiable individuals at all. Although Daltonian conceptions provide convenient terms in which to describe the properties of matter, their original significance has undergone very important changes during the last thirty years.

1. A PARTICLE IS NOT AN INDIVIDUAL

Atomism in its latest form is called quantum mechanics. It has extended its range to comprise, besides ordinary matter, all kinds of radiation, including light—in brief, all forms of energy, ordinary matter being one of them. In the present form of the theory the 'atoms' are electrons, protons, photons, mesons, etc. The generic name is elementary particle, or merely particle. The term atom has very wisely been retained for chemical atoms, though it has become a misnomer.

This essay deals with the elementary particle, more particularly with a certain feature that this concept has acquired—or rather lost—in quantum mechanics. I mean this: that the elementary particle is not an individual; it cannot be identified, it lacks 'sameness.' The fact is known to every physicist, but is rarely given any prominence in surveys readable by non-specialists. In technical language it is covered by saying that the particles 'obey' a new-fangled statistics, either Einstein-Bose or Fermi-Dirac statistics. The implication, far from obvious, is that the unsuspected epithet 'this' is not quite properly applicable to, say, an electron, except with caution, in a restricted sense, and sometimes not at all. My objective here is to explain this point and to give it the thought it deserves. In order to create a foil for the discussion, let me summarize in sections 2–5 what we are usually told about particles and waves in the new physics.

2. CURRENT VIEWS: THE AMALGAMATION OF PARTICLES AND WAVES

Our image of the material world had been made up of two kinds of 'fittings': waves and particles. The former were instanced mainly, if not exclusively, by Maxwell's waves of electromagnetic energy, comprising such as are used in radio, light, X-rays, and gamma-rays. Material bodies were said to consist of particles. One was also familiar with jets of particles, called corpuscular rays, such as cathode rays, beta-rays, alpha-rays, anode rays, etc. Particles would emit and absorb waves. For instance, cathode rays (electrons), when slowed down by colliding with atoms, emit X-rays. The distinction between particles and waves was, however, considered as clear-cut as that between a violin and its sound. An examinee who alleged cathode rays to be waves, or X-rays to be jets of particles, would have got very bad marks.

In the new setting of ideas the distinction has vanished, because it was discovered that all particles have also wave properties, and *vice versa*. Neither of the two concepts must be discarded, they must be amalgamated. Which aspect obtrudes itself depends not on the physical object, but on the experimental device set up to examine it. A jet of cathode rays, for example, produces in a Wilson cloud chamber discrete tracks of water droplets—curved tracks if there is a magnetic field to deflect the electrons, otherwise straight alignments of droplets. We cannot but interpret them as traces of the paths of single electrons. Yet the same jet, after crossing a narrow tube placed at right angles to it and containing crystal powder, will produce on a photographic plate at some distance behind the tube a pattern of concentric circles. This pattern can be understood in all its details when looked upon as the interference pattern of waves, and in no other way. Indeed, it bears a close resemblance to similarly produced X-ray patterns.

The suspicion arises: are the conical jets that impinge on the photographic plate and form the pattern of circles really cathode rays; are they not perhaps secondary X-rays? The suspicion has to be dismissed, for the whole system of circles can be displaced by a magnet, while X-rays can not; moreover, by putting a lead screen with a small hole in it in the place of the photographic plate, a jetlet can be isolated from one of the conical jets and made to display any of the typical particle

characters of cathode rays: it will produce discrete tracks in a cloud chamber; bring about discrete discharges in a Geiger-Müller counter; and charge up a Faraday cage in which it is intercepted.

A vast amount of experimental evidence clinches the conviction that wave characteristics and particle characteristics are never encountered singly, but always in a union; they form different aspects of the same phenomenon, and indeed of all physical phenomena. The union is not a loose or superficial one. It would be quite unsatisfactory to consider cathode rays to consist both of particles and of waves. In the early days of the new theory it was suggested that the particles might be singular spots within the waves, actually singularities in the meaning of the mathematician. The white crests on a moderately rough sea would be a fairly adequate simile. The idea was very soon abandoned. It seems that both concepts, that of waves and that of particles, have to be modified considerably, so as to attain a true amalgamation.

3. CURRENT VIEWS: THE NATURE OF WAVES

The waves, so we are told, must not be regarded as quite real waves. It is true that they produce interference patterns—which is the crucial test that in the case of light had removed all doubts as to the reality of the waves. However, we are now told that all waves, including light, ought rather to be looked upon as 'probability waves.' They are only a mathematical device for computing the probability of finding a particle in certain conditions, for instance (in the above example), the probability of an electron hitting the photographic plate within a small specified area. There it is registered by acting on a grain of silver bromide. The interference pattern is to be regarded as a statistical registration of the impinging electrons. The waves are in this context sometimes referred to as guiding waves—guiding or directing the particles on their paths. The guidance is not to be regarded as a rigid one; it merely constitutes a probability. The clear-cut pattern is a statistical result, its definiteness being due to the enormous number of particles.

Here I cannot refrain from mentioning an objection which is too obvious not to occur to the reader. Something that influences the physical behaviour of something else must not in any respect be called less real than the something it influences—whatever meaning we may give to the dangerous epithet 'real.' It is certainly useful to recall at times that all quantitative models or images conceived by the physicist are, epistemologically, only mathematical devices for computing observable events, but I cannot see that this applies more to, say, light-waves than to, say, oxygen molecules.

4. CURRENT VIEWS: THE NATURE OF PARTICLES (UNCERTAINTY RELATION)

As regards the modification required in the concept of a particle, the stress is on Heisenberg's uncertainty relation. The so-called classical mechanics hinged on Galileo's and Newton's discovery that the thing which in a moving body is determined at any instant by the other bodies in its environment is only and precisely its acceleration, or, in mathematical terms, the second derivatives with respect to time of the co-ordinates. The first derivatives, commonly called the velocity, are therefore to be included in the description of the momentary state of the body, together with the co-ordinates themselves which label its momentary place in space or 'whereness' (or ubiety, to use an antiquated but convenient word). Thus, to describe the momentary state of a particle, two independent data were required: its co-ordinates and their first time derivatives, or ubiety and velocity. According to the new theory less is required, and less is obtainable. Either of the two data can be given with arbitrary accuracy, provided that no store is set on the other, but both cannot be known together with absolute precision. One may not even conceive of both as having absolutely sharp values at the same instant. They mutually blur each other, as it were. Broadly speaking, the product of the latitudes of their respective inaccuracies cannot be reduced below a fixed constant. For an electron, this constant happens to be about 1 if the units centimetre and second are used. Thus, if the velocity of an electron is considered sharp with a latitude of only 1 cm/sec, its location has to be considered as blurred within the latitude of 1 cm. The strangeness does not lie in the mere existence of inaccuracies, for the particle might be a thing of vague and changeable extension, within which slightly different velocities prevailed at different spots. Then, however, a sharp location or ubiety would probably entail a sharply defined velocity and *vice versa*. Actually it is just the other way round.

5. CURRENT VIEWS: THE MEANING OF THE UNCERTAINTY RELATION

Two links connect this strange and certainly very fundamental statement to other parts of the

theory. It can be arrived at by declaring that a particle is equivalent to its guiding wave, and has no characteristics save those indicated by the guiding wave according to a certain code. The code is simple enough. The ubiety is indicated by the extension of the wave, the latitude in the velocity by the range of wave numbers. 'Wave number' is short for reciprocal of the wavelength. Each wave number corresponds to a certain velocity proportional to it. That is the code. It is a mathematical truism that the smaller a wave group, the wider is the (minimum) spread of its wave numbers.

Alternatively, we may scrutinize the experimental procedure for determining either the ubiety or the velocity. Any such measuring device implies a transfer of energy between the particle and some measuring instrument—eventually the observer himself, who has to take a reading. This means an actual physical interference with the particle. The disturbance cannot be arbitrarily reduced, because energy is not exchanged continuously but in portions. We are given to understand that, when measuring one of the two items, ubiety or velocity, we interfere with the other the more violently the higher the precision we aim at. We blur its value within a latitude inversely proportional to the latitude of error allowed in the first.

In both explanations the wording seems to suggest that the uncertainty or lack of precision refers to the attainable knowledge about a particle rather than to its nature. Indeed, by saying that we disturb or change a measurable physical quantity we logically imply that it has certain values before and after our interference, whether we know them or not. And in the first explanation, involving the wave, if we call it a guiding wave how should it guide the particle on its path, if the particle has not got a path? If we say the wave indicates the probability of finding the particle at A, or at B, or at C . . . this seems to imply that the particle is at one, and one only, of these places; and similarly for the velocity. (Actually the wave does indicate both probabilities simultaneously, one by its extension, the other by its wave numbers.) However, the current view does not accept either ubiety or velocity as permanent objective realities. It stresses the word 'finding.' Finding the particle at point A does not imply that it has been there before. We are more or less given to understand that our measuring device has brought it there or 'concentrated' it at that point, while at the same time we have disturbed its velocity. And this does not imply that the velocity 'had' a value. We have only disturbed or changed the probability of finding this or that value of the velocity if we measure it. The implications as to 'being' or 'having' are misconceptions, to be blamed on language. Positivist philosophy is invoked to tell us that we must not distinguish between the knowledge we can obtain of a physical object and its actual state. The two are one.

6. CRITICISM OF THE UNCERTAINTY RELATION

I will not discuss here that tenet of positivist philosophy. I fully agree that the uncertainty relation has nothing to do with incomplete knowledge. It does reduce the amount of information attainable about a particle as compared with views held previously. The conclusion is that these views were wrong and we must give them up. We must not believe that the completer description they demanded about what is really going on in the physical world is conceivable, but in practice unobtainable. This would mean clinging to the old view. Still, it does not necessarily follow that we must give up speaking and thinking in terms of what is really going on in the physical world. It has become a convenient habit to picture it as a reality. In everyday life we all follow this habit, even those philosophers who opposed it theoretically, such as Bishop Berkeley. Such theoretical controversy is on a different plane. Physics has nothing to do with it. Physics takes its start from everyday experience, which it continues by more subtle means. It remains akin to it, does not transcend it generically, it cannot enter into another realm. Discoveries in physics cannot in themselves—so I believe—have the authority of forcing us to put an end to the habit of picturing the physical world as a reality.

I believe the situation is this. We have taken over from previous theory the idea of a particle and all the technical language concerning it. This idea is inadequate. It constantly drives our mind to ask for information which has obviously no significance. Its imaginative structure exhibits features which are alien to the real particle. An adequate picture must not trouble us with this disquieting urge; it must be incapable of picturing more than there is; it must refuse any further addition. Most people seem to think that no such picture can be found. One may, of course, point to the circumstantial evidence (which I am sorry to say is not changed by this essay) that in

fact none has been found. I can, however, think of some reasons for this, apart from the genuine intricacy of the case. The palliative, taken from positivist philosophy and purporting to be a reasonable way out, was administered fairly early and authoritatively. It seemed to relieve us from the search for what I should call real understanding; it even rendered the endeavour suspect, as betraying an unphilosophical mind—the mind of a child who regretted the loss of its favourite toy (the picture or model) and would not realize that it was gone for ever. As a second point, I submit that the difficulty may be intimately connected with the principal subject of this paper, to which I shall now turn without further delay. The uncertainty relation refers to the particle. The particle, as we shall see, is not an identifiable individual. It may indeed well be that no individual entity can be conceived which would answer the requirements of the adequate picture stated above.

It is not at all easy to realize this lack of individuality and to find words for it. A symptom is that the probability interpretation, unless it is expressed in the most highly technical language of mathematics, seems to be vague as to whether the wave gives information about one particle or about an *ensemble* of particles. It is not always quite clear whether it indicates the probability of finding 'the' particle or of finding 'a' particle, or indicates the likely or average number of particles in, say, a given small volume. Moreover the most popular view on probability tends to obliterate these differences. It is true that exact mathematical tools are available to distinguish between them. A point of general interest is involved, which I will explain. A method of dealing with the problem of many particles was indicated in 1926 by the present writer. The method uses waves in many-dimensional space, in a manifold of $3N$ dimensions, N being the number of particles. Deeper insight led to its improvement. The step leading to this improvement is of momentous significance. The many-dimensional treatment has been superseded by so-called second quantization, which is mathematically equivalent to uniting into one three-dimensional formulation the cases $N = 0, 1, 2, 3 \ldots$ (to infinity) of the many-dimensional treatment. This highly ingenious device includes the so-called new statistics, with which we shall have to deal below in much simpler terms. It is the only precise formulation of the views now held, and the one that is always used. What is so very significant in our present context is that one cannot avoid leaving indeterminate the number of the particles dealt with. It is thus obvious that they are not individuals.

7. THE NOTION OF A PIECE OF MATTER

I wish to set forth a view on matter and the material universe, to which Ernst Mach [1], Bertrand Russell [2], and others were led by a careful analysis of concepts. It differs from the popular view. We are, however, not concerned with the psychological origin of the concept of matter but with its epistemological analysis. The attitude is so simple that it can hardly claim complete novelty; some pre-Socratics, including the materialist Democritus [3], were nearer to it than were the great men who resuscitated science and moulded it during the seventeenth to nineteenth centuries.

According to this view, a piece of matter is the name we give to a continuous string of events that succeed each other in time, immediately successive ones being as a rule closely similar. The single event is an inextricable complex of sensates, of associated memory images, and of expectations associated with the former two. The sensates prevail in the case of an unknown object, say a distant white patch on the road, which might be a stone, snow, salt, a cat or a dog, a white shirt or blouse, a handkerchief. Even so, within the ensuing string of events we usually know from general experience how to discount the changes caused by motions of our own body, in particular of our direction of sight. As soon as the nature of the object is recognized, images and expectations begin to prevail. The latter concern sensations as hard, soft, heavy, flexible, rough, smooth, cold, salty, etc., associated with the image of touching and handling; they also concern spontaneous movements or noises such as barking, mewing, shouting, etc. It should be noted that I am not speaking of our thoughts or considerations about the object, but of what forms part and parcel of our perception of it—of what it is to us. However, the limit is not sharp. As our familiarity with a piece of matter grows, and in particular as we approach its scientific aspect, the range of expectations in regard to it widens, eventually to include all the information science has ascertained, e.g. melting point, solubility, electric conductivity, density, chemical and crystalline structure, and so on. At the same time, the momentary sensational core recedes in relevance the more the object becomes familiar to us, whether by scientific knowledge or by everyday use.

8. INDIVIDUALITY OR 'SAMENESS'

After a certain wealth of association has come to outshine the core of sensates, the latter is no longer needed to keep the complex together. It persists even when the contact of our senses with the object temporarily ceases. And more than that: the complex is latently conserved even when the whole string is interrupted by our turning away from the object to others and forgetting all about it. Indeed, this is not exceptional, but a rule which—since we sometimes sleep—has no exception. But we have adopted the useful device of filling these gaps. We supplement the missing parts of the strings relating to pieces of matter in our nearer and farther surroundings, to cover the periods when we neither watch them nor think of them. When a familiar object re-enters our ken, it is usually recognized as a continuation of previous appearances, as being the same thing. The relative permanence of individual pieces of matter is the most momentous feature of both everyday life and scientific experience. If a familiar article, say an earthenware jug, disappears from your room, you are quite sure somebody must have taken it away. If after a time it reappears, you may doubt whether it really is the same one—breakable objects in such circumstances are often not. You may not be able to decide the issue, but you will have no doubt that the doubtful sameness has an indisputable meaning—that there is an unambiguous answer to your query. So firm is our belief in the continuity of the unobserved parts of the strings !

No doubt the notion of individuality of pieces of matter dates from time immemorial. I suppose animals must have it in some way, and a dog, when seeking for his ball that has been hidden, displays it very plainly. Science has taken it over as a matter of course. It has refined it so as safely to embrace all cases of apparent disappearance of matter. The idea that a log which burns away first turns into fire, then into ashes and smoke, is not alien to the primitive mind. Science has substantiated it; though the appearance in bulk may change, the ultimate constituents of the matter do not. This was (in spite of his occasional scepticism mentioned above) the teaching of Democritus. Neither he nor Dalton doubted that an atom which was originally present in the block of wood is afterwards either in the ashes or in the smoke.

9. THE BEARING ON ATOMISM

In the new turn of atomism that began with the papers of Heisenberg and of de Broglie in 1925 such an attitude has to be abandoned. This is the most startling revelation emerging from the ensuing development, and the feature which in the long run is bound to have the most important consequences. If we wish to retain atomism we are forced by observed facts to deny the ultimate constituents of matter the character of identifiable individuals. Up to recently, atomists of all ages, for all I know, had transferred that characteristic from visible and palpable pieces of matter to the atoms, which they could not see or touch or observe singly. Now we do observe single particles; we see their tracks in the cloud chamber and in photographic emulsions; we register the practically simultaneous discharges caused by a single swift particle in two or three Geiger counters placed at several yards' distance from each other. Yet we must deny the particle the dignity of being an absolutely identifiable individual. Formerly, if a physicist were asked what stuff the atoms themselves were made of, he might smile and shirk the answer. If the inquirer insisted on the question whether he might imagine them as small unchangeable bits of ordinary matter, he would get the smiling reply that there was no point in doing so but that it would do no harm. The formerly meaningless question has now gained significance. The answer is definitely in the negative. An atom lacks the most primitive property we associate with a piece of matter in ordinary life. Some philosophers of the past, if the case could be put to them, would say that the modern atom consists of no stuff at all but is pure shape.

10. THE MEANING OF THE NEW STATISTICS

We must at last proceed to give the reasons for this change of attitude in a more comprehensible form than at the end of section 6. It rests on the so-called new statistics. There are two of them. One is the Bose-Einstein statistics, whose novelty and relevance were first stressed by Einstein. The other is the Fermi-Dirac statistics, of which the most pregnant expression is Pauli's exclusion principle. I shall try to explain the new statistics, and its relation to the old classical or Boltzmann statistics, to those who have never heard about such things and perhaps may be puzzled by what 'statistics' means in this context. I shall use an instance from everyday life. It may seem childishly simple, particularly because we have to choose small numbers—actually 2 and 3—in order to make the arithmetic surveyable. Apart from this, the illustration is completely adequate and covers the actual situation.

Three schoolboys, Tom, Dick, and Harry, deserve a reward. The teacher has two rewards to distribute among them. Before doing so, he wishes to realize for himself how many different distributions are at all possible. This is the only question we investigate (we are not interested in his eventual decision). It is a statistical question: to count the number of different distributions. The point is that the answer depends on the nature of the rewards. Three different kinds of reward will illustrate the three kinds of statistics.

(*a*) The two rewards are two memorial coins with portraits of Newton and Shakespeare respectively. The teacher may give Newton either to Tom or to Dick or to Harry, and Shakespeare either to Tom or to Dick or to Harry. Thus there are three times three, that is nine, different distributions (classical statistics).

(*b*) The two rewards are two shilling-pieces (which, for our purpose, we must regard as indivisible quantities). They can be given to two different boys, the third going without. In addition to these three possibilities there are three more: either Tom or Dick or Harry receives two shillings. Thus there are six different distributions (Bose-Einstein statistics).

(*c*) The two rewards are two vacancies in the football team that is to play for the school. In this case two boys can join the team, and one of the three is left out. Thus there are three different distributions (Fermi-Dirac statistics).

Let me mention right away: the *rewards* represent the particles, two of the same kind in every case; the boys represent states the particle can assume. Thus, 'Newton is given to Dick' means: the particle Newton takes on the state Dick.

Notice that the counting is natural, logical, and indisputable in every case. It is uniquely determined by the nature of the objects: memorial coins, shillings, memberships. They are of different categories. Memorial coins are individuals distinguished from one another. Shillings, for all intents and purposes, are not, but they are still capable of being owned in the plural. It makes a difference whether you have one shilling, or two, or three. There is no point in two boys exchanging their shillings. It does change the situation, however, if one boy gives up his shilling to another. With memberships, neither has a meaning. You can either belong to a team or not. You cannot belong to it twice over.

Experimental evidence proves that statistical counts referring to elementary particles must never follow the pattern (*a*), but must follow either (*b*) or (*c*). Some hold that for all genuinely elementary particles (*c*) is competent. Such particles, electrons for instance, correspond to membership in a club; I mean to the abstract notion of membership, not to the members. Any person eligible to membership in that club represents a well-defined state an electron can take on. If the person is a member, that means there is an electron in that particular state. According to Pauli's exclusion principle, there can never be more than one electron in a particular state. Our simile renders this by declaring double membership meaningless—as in most clubs it would be. In the course of time the list of members changes, and membership is now attached to other persons: the electrons have gone over into other states. Whether you can, in a loose way, speak of a certain membership going over from Dick to Tom, thence from Tom to Harry, etc., depends on the circumstances. They may suggest this view, or they may not, but never in an absolute fashion. In this our simile is perfect, for it is the same with an electron. Moreover, it is quite appropriate to consider the number of members as fluctuating. Indeed, electrons too are created and annihilated.

The example may seem odd and inverted. One might think, 'Why cannot the people be the electrons and various clubs their states? That would be so much more natural.' The physicist regrets, but he cannot oblige. And this is just the salient point: the actual statistical behaviour of electrons cannot be illustrated by any simile that represents them by identifiable things. That is why it follows from their actual statistical behaviour that they are not identifiable things.

The case (*b*), illustrating Einstein-Bose statistics, is competent for light quanta (photons), *inter alia*. It hardly needs discussion. It does not strike us as so strange for the very reason that it includes light, i.e. electro-magnetic energy; and energy, in pre-quantum times, had always been thought of in very much the way our simile represents it, viz. as having quantity, but no individuality.

11. RESTRICTED NOTION OF IDENTITY

The most delicate question is that of the states of, say, an electron. They are, of course, to be defined not classically, but in the light of the uncertainty relation. The rigorous treatment referred to at the end of section 6 is not really based on the notion of 'state of one electron' but on that of 'state of the assembly of electrons.' The whole list of members of the club, as it were, has to be envisaged together—or rather several membership

lists, corresponding to the several kinds of particles that go to compose the physical system under consideration. I mention this, not to go into details about it, but because, taken rigorously, the club simile has two flaws. First, the possible states of an electron (which we had assimilated to the persons eligible for membership) are not absolutely defined; they depend on the arrangement of the—actual or imagined—experiment. Given this arrangement, the states are well-defined individuals, which the electrons are not. They also form—and this is the second flaw of the simile—a well-ordered manifold. That is, there is a meaning in speaking of neighbouring states as against such as are farther remote from each other. Moreover, I believe it is true to say that this order can be conceived in such a fashion that, as a rule, whenever one occupied state ceases to be occupied, a neighbouring state becomes occupied.

This explains that, in favourable circumstances, long strings of successively occupied states may be produced, similar to those contemplated in sections 7 and 8. Such a string gives the impression of an identifiable individual, just as in the case of any object in our daily surrounding. It is in this way that we must look upon the tracks in the cloud chamber or in a photographic emulsion, and on the (practically) simultaneous discharges of Geiger counters set in a line, which discharges we say are caused by the same particle passing one counter after another. In such cases it would be extremely inconvenient to discard this terminology. There is, indeed, no reason to ban it, provided we are aware that, on sober experimental grounds, the sameness of a particle is not an absolute concept. It has only a restricted significance and breaks down completely in some cases.

In what circumstances this restricted sameness will manifest itself is fairly obvious: namely, when only few states are occupied in the region of the state-manifold with which we are concerned, or, in other words, when the occupied states are not too crowded in that region, or when occupation is a rare event—the terms few, crowded, and rare all referring to the state-manifold. Otherwise, the strings intermingle inextricably and reveal the true situation. In the last section we shall formulate the quantitative condition for the prevailing of restricted individuality. Now we ask what happens when it is obliterated.

12. CROWDEDNESS AND WAVE ASPECT

One gains the impression that according as the individuality of the particles is wiped out by crowding, the particle aspect becomes altogether less and less expedient and has to be replaced by the wave aspect. For instance, in the electronic shell of an atom or molecule the crowding is extreme, almost all the states within a certain region being occupied by electrons. The same holds for the so-called free electrons inside a metal. Indeed, in both cases the particle aspect becomes entirely incompetent. On the other hand, in an ordinary gas the molecules are extremely rare in the wide region of states over which they spread. No more than one state in 10,000 or so is occupied. And, indeed, the theory of gases, based on the particle aspect, was able to attain great perfection long before the wave nature of ordinary matter was discovered. (In the last remark I have been speaking of the molecules as if they were ultimate particles; this is legitimate as far as their translatory motion is concerned.)

It is tempting to assign to the two rivals, the particle aspect and the wave aspect, full competences in the limiting cases of extreme 'rarefaction' and extreme 'crowding' respectively. This would separate them, as it were, with only some sort of transition required for the intermediate region. This idea is not entirely wrong, but it is also far from correct. One may remember the interference patterns referred to in section 2 in evidence of the wave nature of the electron. They can be obtained with an arbitrarily faint bundle of cathode rays, provided the exposure is prolonged. Thus a typical wave phenomenon is produced here, irrespective of crowding. Another instance is this. A competent theoretical investigation of the collision of two particles, whether of the same or of different kind, has to take account of their wave nature. The results are duly applied to the collisions of cosmic ray particles with atomic nuclei in the atmosphere, both being extremely rarefied in every sense of the word. But perhaps this is trivial; it only means that even an isolated particle, which gives us the illusion of transitory individuality, must yet not be likened to a classical particle. It remains subject to the uncertainty relation, of which the only tolerable image is the guiding wave group.

13. THE CONDITION FOR THE PARTICLE ASPECT

The following is the quantitative condition for strings to develop which counterfeit individuals and suggest the particle aspect: the product of the momentum p and the average distance l between neighbouring particles must be fairly large

compared with Planck's constant h; thus

$$pl >> h.$$

(The momentum p—and not the velocity—is the thing we should really have referred to when, in sections 4 and 5, we dealt with the uncertainty relation; p is simply the product of the mass and the velocity, unless the latter is comparable with that of light.)

A large l means a low density in ordinary space. What matters, however, is the density in the manifold of states—or phase space, to use the technical term. That is why the momentum p comes in. It is gratifying to remember that those very obvious strings—visible tracks in the cloud chamber or in the photographic emulsion, and simultaneous discharges of aligned counters—are all produced by particles with comparatively very large momentum.

The above relation is familiar from the theory of gases, where it expresses the condition which must be fulfilled in very good approximation in order that the old classical particle theory of gases should apply in very good approximation. This theory has to be modified according to quantum theory when the temperature is very low and at the same time the density very high, so that the product pl is no longer very large compared with h. This modification is called the theory of degenerate gases, of which the most famous application is that by A. Sommerfeld to the electrons inside a metal; we have mentioned them before as an instance of extreme crowding.

There is the following connection between our relation and the uncertainty relation. The latter allows one at any moment to distinguish a particle from its neighbours by locating it with an error considerably smaller than the average distance l. But this entails an uncertainty in p. On account of it, as the particle moves on, the uncertainty in the location grows. If one demands that it still remain well below l after the particle has covered the distance l, one arrives precisely at the above relation.

But again I must warn of a misconception which the preceding sentences might suggest, viz. that crowding only prevents us from registering the identity of a particle, and that we mistake one particle for the other. The point is that they are not individuals which could be confused or mistaken one for another. Such statements are meaningless.

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SIXTH INTERNATIONAL CONGRESS FOR THE HISTORY OF SCIENCE

The Sixth International Congress for the History of Science, and the Twelfth Congress of the International Society for the History of Medicine, will be held at Amsterdam on 14th to 21st August, 1950. It is being organized by the *Genootschap voor Geschiedenis der Geneeskunde, Wiskunde en Natuurwetenschappen* at Leiden, under the auspices of the International Academy and the International Union for the History of Science.

There will be five sections of the Congress, viz. (i) history of mathematics, physics, astronomy, geography, and geology; (ii) history of chemistry, mineralogy, pharmacy, and biology; (iii) history of applied science and technology; (iv) history of medicine; and (v) general problems, methods, and philosophy of science. The fourth section is at the same time the XIIth Congress of the *Société Internationale d'Histoire de la Médecine*.

It is intended to publish the 'Transactions of the Amsterdam Congress' in one volume in the course of 1951. Part of the communications will appear earlier in the *Archives Internationales d'Histoire des Sciences*, as was the case with the papers presented at the Lausanne Congress of 1947.

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Thomas Wright of Durham

F. A. PANETH

Although Thomas Wright's work does not place him on the same plane as such famous astronomers as Copernicus or Newton, it certainly entitles him to greater appreciation than he is generally accorded. In particular he was the first to explain, in his *Original Theory*, published in 1750, that the density of stars in the Milky Way was apparent rather than real. In postulating a disk-like shape of the stellar system he anticipated Herschel by 35 years.

Two hundred years ago, in 1750, Thomas Wright's *Original Theory or New Hypothesis of the Universe* was published in London. It was printed with the help of subscriptions, mainly from high society, and did not interest any English astronomer.

In 1837 a second edition was prepared in the United States by the well-known naturalist C. S. Rafinesque. He wrote in the 'Preface of the American Editor': 'Our worthy Author has met with total neglect at the hands of his blinded countrymen. We have not yet found him quoted anywhere, and a Philosopher and Astronomer, equal to Plato, Copernic, Newton and Herschel, was to this day nearly unknown, until we found his work, and determined at once to restore him to life and fame.'

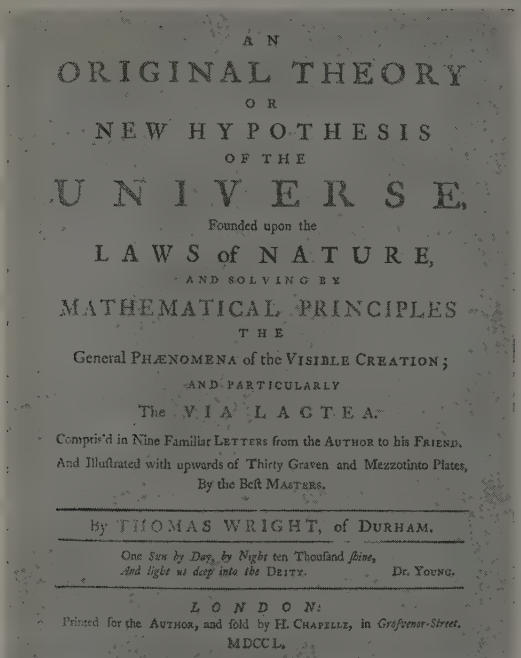
Rafinesque was right that in England Thomas Wright was completely forgotten. He was mistaken in the hope that his own effort would bring fame to him (his inconspicuous little brochure, published in Philadelphia without any plates, is today of greater rarity than Wright's impressive volume—at least in England, where the British Museum seems to possess the only copy). Rafinesque was carried too far by his enthusiasm in putting Thomas Wright on a level with the greatest names in astronomy; and he did not know that, long before his days, some of Wright's ideas had induced Immanuel Kant to compose in his East Prussian solitude his own theory of the universe, in which he gives full credit to the inspiration received from Wright.

It is due to Kant, and not to Rafinesque, that Wright's name is not forgotten. From Kant's work the astronomers Arago in Paris and Struve in St. Petersburg learned of him, and in 1848 their references prompted the London mathematician De Morgan to publish abstracts from his book and to 'submit that his name ought to be enrolled in the list of discoverers' [3]. De Morgan's perspective is distorted by his ignorance of Kant's writings, but the relationship between the two thinkers was discussed more fully in 1896 by the Durham professor of mathematics R. A. Sampson [4], in 1900 by the Glasgow professor of divinity W. Hastie [5], and more recently (in 1941) in an article in *The Durham University Journal* which was reprinted in the periodical *The Observatory* [6].

The aim of the present publication is to draw attention to the bicentenary of Thomas Wright's principal work, and to supplement all that has previously been written about him by the inclusion of illustrations taken from his book.

Thomas Wright was not only a scientist but also an artist, or at least a craftsman skilled in designing and engraving. He was not a good writer, and quotations from the printed text, without the pictures, can give no true impression of the character of his books. Two years before the appearance of his *Original Theory* he published a description of Irish antiquities in a richly illustrated book *Louthiana*, the fruit of extended studies in that part of Ireland. The two works differ so much in character that in Allibone's *Dictionary of English Literature* they are ascribed to two different authors, both of the name of Thomas Wright. They have, however, the common feature of containing very carefully executed etchings, made either by Wright himself or drawn under his close supervision. He also enjoyed some reputation as an architect; few of the thousands of visitors to Durham Cathedral are aware that the battlements on the western towers were rebuilt early in the nineteenth century after a design by Thomas Wright. His own sketch is still preserved in the library of the Durham Chapter.

The title page of his *Original Theory* indicates that he considered his explanation of the Milky Way as the most important part (see figure 1), but only two of the thirty-two full-size plates included in the book are directly connected with this subject. The first is a representation of the



AN
ORIGINAL THEORY
OR
NEW HYPOTHESIS
OF THE
UNIVERSE,
Founded upon the
LAWS of NATURE,
AND SOLVING BY
MATHEMATICAL PRINCIPLES
THE
General PHÆNOMENA of the VISIBLE CREATION;
AND PARTICULARLY
The VIA LACTEA.
Compris'd in Nine Familiar LETTERS from the AUTHOR to his FRIEND.
And Illustrated with upwards of Thirty Graven and Mezzotinto Plates,
By the Best MASTERS.

By THOMAS WRIGHT, of DURHAM.

One *Sun by Day, by Night* ten Thousand *shine,*
And light us deep into the DEITY. Dr. YOUNG.

LONDON:
Printed for the AUTHOR, and sold by H. CHAPELLE, in *Grosvenor-Street.*
MDCCL.

FIGURE 1 – *Title Page of the* Original Theory.

Milky Way as seen through a telescope (see figure 5). Today we are spoilt by the wealth and beauty of photographic illustrations in popular scientific works, but it is unlikely that before Wright such fine pictures had ever been added to an astronomical treatise. Two other mezzotint plates of equal excellence show the Pleiades (see figure 6) and a cluster in Perseus.

The second plate devoted to the Milky Way is a diagram (see figure 8), as are most of the illustrations in the *Original Theory*. In this one, Wright demonstrates why, in his opinion, the phenomenon of the Milky Way is not due to any crowding together of stars in a belt surrounding the Sun, but is only an optical effect, originating from the peculiar shape of the star system to which our sun belongs. Assuming it to be much more extended in two dimensions of space than in the third, he could easily prove that, if we are placed somewhere near the middle, the stars must appear to us in greater density, roughly in a circle, although the average distance between them may be everywhere the same. This circle is the Galaxy.

Thomas Wright was certainly entitled to call this an 'original theory.' Astronomers had just started to prove by telescopic observation that the Milky Way actually consisted not of a nebulous mass but of a great number of stars, too numerous to be seen distinctly by the naked eye, but it was entirely new to consider this high concentration of stars as only apparent, owing to the peculiar situation of the Sun relative to the other stars in our part of the universe. Thirty-five years later Herschel, on the basis of his observations, and quite in ignorance of Thomas Wright's ideas, came to the conclusion that the stars 'in our nebula' were arranged in the form of a disk, and since his days much work has been done to define the exact shape of this disk and the place of the Sun therein. The essential correctness of Herschel's view is today beyond doubt, and it is fundamentally the same as that taken by Wright in his *Original Theory*.

Kant never saw a copy of Wright's book. All his knowledge of it came from a short though very competent abstract in a Hamburg periodical which he happened to read. He accepted Wright's explanation of the Milky Way but considered it only as a remark which Wright himself 'had not used for any very important purpose, and the useful application of which he had not sufficiently observed.' Wright's conception is a geometrical one, and correct as far as it goes. Kant's is dynamical and evolutionary; on the basis of the law of universal gravitation he tries to explain the way in which the universe developed from an initial uniform distribution of particles. The title he gave to his book, *Allgemeine Naturgeschichte und Theorie des Himmels*, indicated that he was outlining the history of the world; it might be translated as 'Universal Theory of Celestial Evolution,' an aim far beyond anything that Wright attempted.

This is not the place to discuss in detail the relation of Kant's system of the world to that of Thomas Wright. One basic difference, however, might be mentioned, as it has apparently not been noticed before. Wright's conception of the universe can be seen from several of his plates (see figures 7 and 9). The many star systems he assumed to exist are always depicted as enclosed by spheres or, in cross-section, by circles (in the latter case the 'eye of providence' may be discerned in the centre of each), and many readers may have wondered what he meant by these boundaries of the star systems. No explanation is given in the *Original Theory*, but he drew a similar diagram for an earlier work, *The Use of the Globes*, and here he stated that his scheme was 'founded upon This Hypothesis, That the Stars are so many Suns; that each of these Stars or Suns is attended, (as ours is), by a proper number

IGURE 2 – *Westerton Folly, which Wright built, and proposed fit up as a private observatory.*

FIGURE 3 – *Thomas Wright.* (*Reduced from an engraving in quarto which is prefixed to a few copies of* Clavis Coelestis *and of the* Original Theory.)

FIGURE 4 – *Wright's home, Byer's Green Hall.*

FIGURE 5—*The Milky Way as seen 'through a very good reflector.'*
(*Figures* 5–10 *are from the* Original Theory.)

FIGURE 6—*The Pleiades, as seen 'thro' a one Foot reflecting Telescope.'*

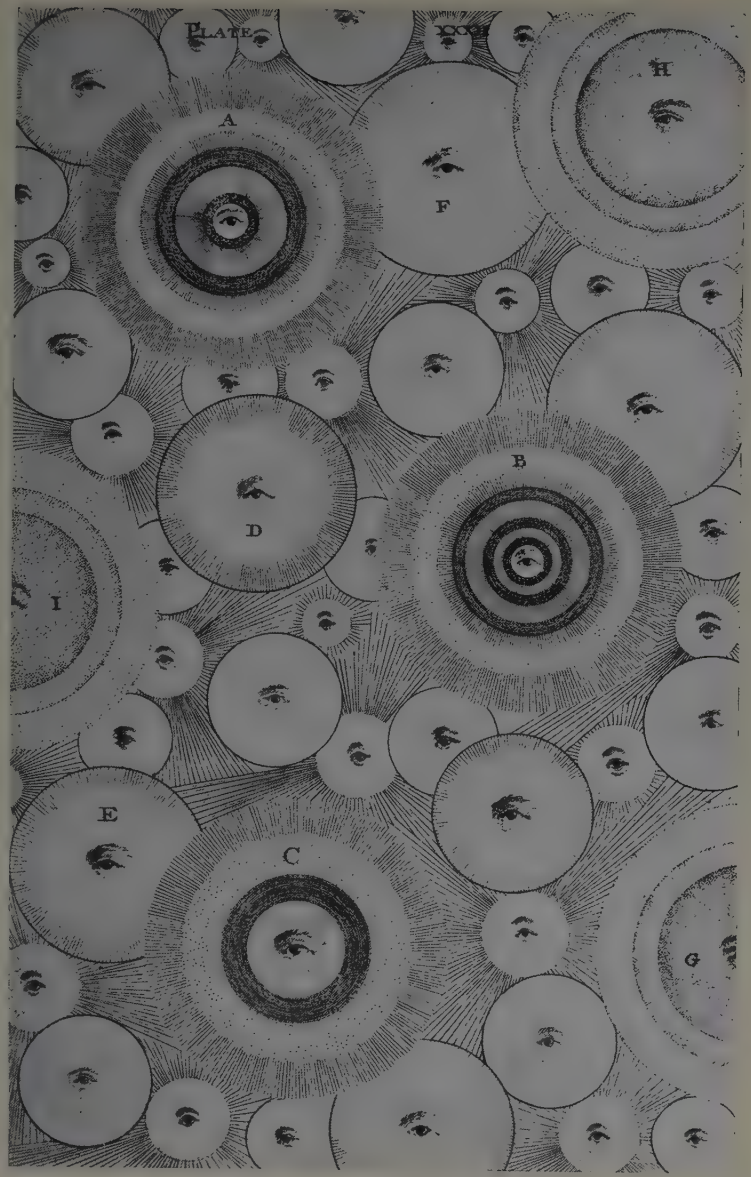


FIGURE 7 – '*A finite View of Infinity.*'

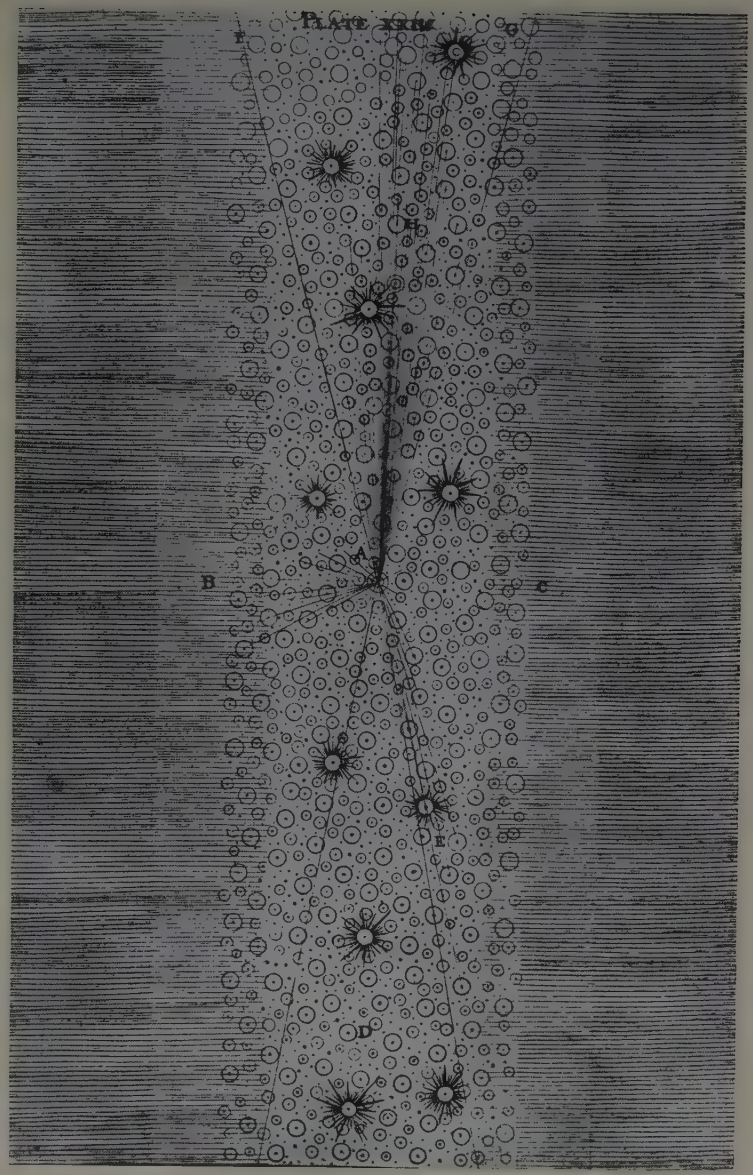


FIGURE 8 – *Diagram of the Milky Way.*

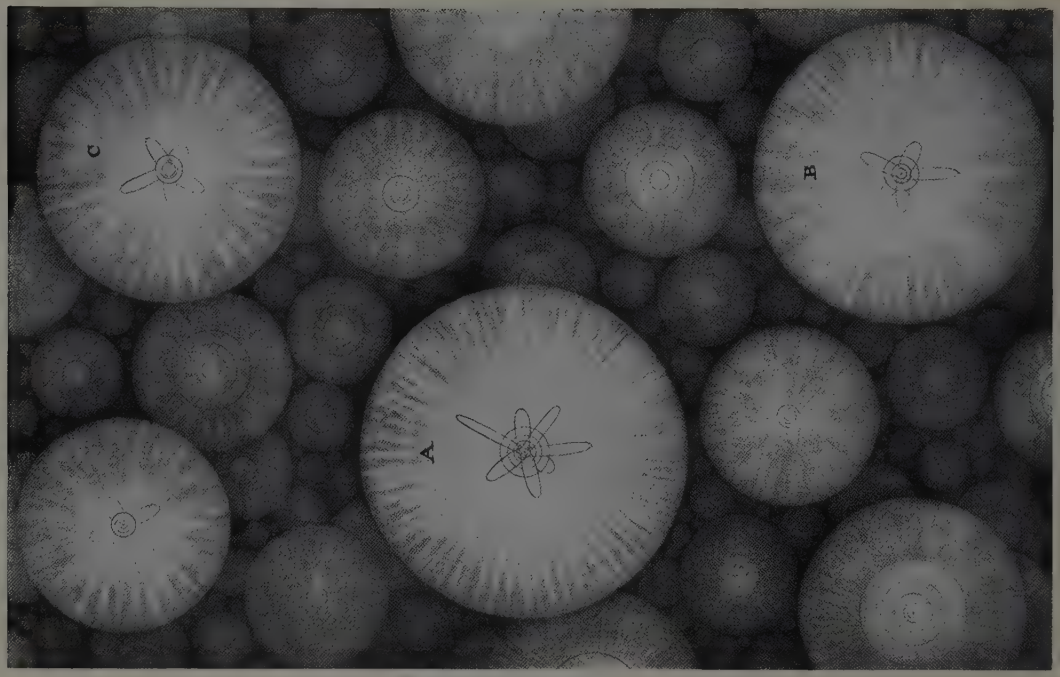


FIGURE 9 – '*Perspective View of the visible Creation.*'

of Planets and Comets; and that each hath a gravitating Power independent of each other,' so that 'these several Systems cannot interfere with one another.' From this passage it is clear that Wright meant by the enveloping spheres represented on his plates the boundaries of the independent forces of gravitation. This queer idea shows very strikingly what a gap there was between his natural philosophy and that of Kant, who assumed the validity of Newton's law throughout the whole universe, attraction being 'unlimited and universal,' reaching 'to all the distance of nature's infinitude.'

Among the many diagrams in Wright's book there are two which are meant not only to be illustrations in a qualitative way, but to help professional astronomers in their studies on the position of stars. Wright firmly believed that the 'fixed' stars were moving, and in order to enable future astronomers to establish this fact beyond doubt he made an attempt to transmit to them the relative positions of the main stars in the Pleiades and in Perseus exactly as they appeared to him. As his fine pictures of these constellations, mentioned above, were obviously not suitable for the delicate task, he supplemented them by geometrical drawings. From figure 10, which represents the Pleiades, can be seen the way in which he connected the stars by many straight lines; he considered their positions as the corners of triangles, and hoped that any movements of the stars could in future be detected by the disappearance of such regularities as shown in his plates. It is rather strange, but very characteristic, that he relied entirely on engraved plates for such difficult comparisons, and did not trouble to give numbers for the positions of the stars he had observed. Moreover, if the Pleiades should move as a group—as they actually do—their relative positions would not show any variation from his drawings.

Wright was obviously always happy if he could exchange the pen for the engraving tool; the figures he drew were of no real value for the purpose of observing star movements, but we may perhaps see in them an inkling of the decisive help which today the infinitely more exact photographs of the stars give to astronomy. When modern observatories store thousands of photographic plates for future comparisons they do in

principle exactly what Thomas Wright intended with his laboriously prepared copper plates.

To do justice to him and to his peculiarities as an author we must not forget the kind of readers he had to reckon with. The subscribers to his book were the same gentlefolk whom he taught orally as an instructor, and this may explain not only the unnecessarily large number of illustrations but also his habit, so distracting to modern readers, of constantly interrupting his scientific discussions by theological digressions, exhortations, and quotations from poets. The scientific contents of the *Original Theory* could easily have been presented in less than half of its eighty-four pages, and Wright's interesting views on various astronomical questions would then have stood a better chance of being noted by his scientific contemporaries. He was probably completely 'original' only in his explanation of the Milky Way, but it is certainly noteworthy that in his book he inclines also to the modern interpretation of

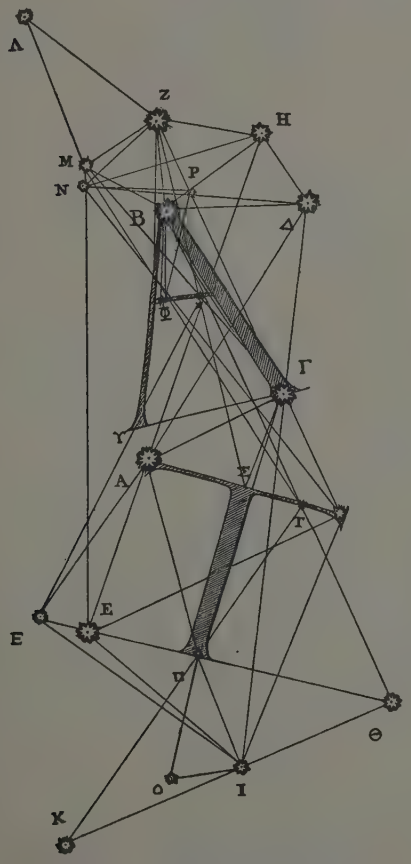


FIGURE 10 – *Diagram of the Pleiades.*

Saturn's ring as consisting of small particles. Some writers on astronomy give him credit for the conjecture that 'could we view Saturn thro' a Telescope capable of it, we should find his Rings no other than an infinite number of lesser Planets, inferior to those we call his Satellites.' Kant, however, who discusses the theoretical difficulties, following from Kepler's law, which beset the assumption of a solid ring, mentions that as early as 1705 Cassini had suggested that Saturn's ring might be a swarm of small satellites. It is quite likely that Wright too—who cared less than Kant for exact references—had seen Cassini's paper. On the other hand, it is possible that he had no forerunners in his interpretation of the nebulae as systems similar to the galaxy, and that this was one of the points in which he influenced Kant—although the Hamburg abstract which the latter saw does not make Wright's opinion clear. In any case, Kant's main argument for this interpretation of the nebulae, viz. their appearance as elliptical figures, is not to be found in Wright's book.

A merit of De Morgan's article, mentioned above, is that of having drawn attention to the only source of biographical information about Thomas Wright. Shortly after his death a personal friend, George Allan of Darlington, published anonymously in the *Gentleman's Magazine* 'A Sketch of the Character of Mr. Thomas Wright, late of Byer's Green Lodge, in the County of Durham' [1]. Unfortunately Allan was an antiquary without scientific judgment; he was mainly impressed by the social success of his hero. Thomas Wright, the son of a carpenter, born in 1711 in the little village of Byer's Green six miles from Durham, hampered in his education by a defect in speech, had in middle life become the fashionable tutor in astronomy and mathematics of the ladies of the English aristocracy, spending his days on the estates of dukes and earls, hunting and dining with them. To one of them he owed the annuity which enabled him to reside in later years as a gentleman of leisure in the large house which he built for himself in his native village, and the interior of which he decorated most elaborately with pictures, prints, and verses from his favourite poets. Here he lived, unmarried, in philosophic serenity, among books and instruments, and occupied with plans for the erection of a private observatory, until he died in 1786. He is buried in the churchyard of St Andrew's at Bishop Auckland.

He was soon forgotten. The author of the obituary note naturally did not succeed in

awakening the interest of scientists by tracing the picture of a tutor in noble families who excelled in the popularization of astronomy. He gives hardly any information about Wright's serious studies, but mentions admiringly his erection, in the gardens of his rich patrons, of large models of the solar system, the construction of an 'astronomical fan for the ladies,' and the embellishment of his various books by copper plates. All he has to say in praise of the *Original Theory* is just: 'it is illuminated with a great many plates'; but he was at least interested in these plates and purchased the original coppers out of Wright's estate. He also bought his collection of pictures and prints, but a peculiar misfortune seems to have prevented the survival of any of these relics. Allan's collection passed into the possession of the Newcastle Literary and Philosophical Society, and it is not unlikely that they contained books and pictures, perhaps also instruments, from Thomas Wright's house; but a fire destroyed much of the Society's property in 1893, and nothing relating to Wright can be found there today. His house in Byer's Green is still standing, no longer as the elegant residence of a retired gentleman but as three small flats; it is closely surrounded by cheap houses which take the place of Thomas Wright's beloved gardens and orchards. In his days no house was less than a hundred yards from his own. The west terrace on which he liked to dine in the open air has also vanished, so that it is not quite easy to recognize in the drab 'Byer's Green Hall' of today (see figure 4) the eighteenth-century residence of which he himself once gave a glowing description in a letter to a friend [2]. Still less has survived of the 'composition of dials' Thomas Wright erected on the pier at the mouth of Sunderland harbour; it must have been a substantial piece, because he received a gratuity of 20 guineas for it, and a description was published at the expense of the town; but the pier was reconstructed in 1786, and nothing is known about the fate of Thomas Wright's sundials.

One structure, however, seems to have been preserved exactly in the state in which Thomas Wright left it: the 'gothic tower on one of the highest hills in the country,' as he calls it (see figure 2). It belongs to the little village of Westerton, two miles distant from Wright's residence in Byer's Green. It was meant to become his private observatory, but was never used as such because he died before he had equipped it. Most likely it was never used for anything, if we disregard its service as an observation post during the last war. This seems to be implied by the name 'Westerton Folly' under which it is known locally, by the great difficulty encountered in an endeavour to discover its present owner and to get access to it, and by its complete emptiness. The spiral wooden staircase within lacks a few steps and is far from safe, but whoever climbs to the top of the tower will be surprised by the magnificent view it commands of the surrounding countryside, with Durham cathedral in the distance. Its place was certainly well chosen.

The University of Durham celebrated the 200th anniversary of the publication of Thomas Wright's *Original Theory* by an exhibition of his books—one of them existing only as a single copy recently purchased for Durham—and the unveiling of a memorial tablet at his observatory tower. It also invited speakers from other universities to give addresses on Thomas Wright and the general scientific background of his time. Nobody will try to follow Rafinesque and put Thomas Wright on the same level as Newton, but it is felt that too few people still know exactly what Wright's merits are, and that his *Original Theory* has become a not unimportant link in the history of astronomy. What Rafinesque valued most, the florid passages in Wright's last letter on theological and moral principles (which he believed to be localized in the centre of the universe), are just those which Kant treats with hardly concealed irony and dismisses briefly as 'fanatical enthusiasm.' Neither Rafinesque nor Wright's friend Allan could 'restore him to life and fame,' because what they admired, and what no doubt Wright himself considered important, was either irrelevant or could not stand serious criticism. On the other hand, his one great idea, the explanation of the Milky Way, does not seem to have occupied his thoughts in later years; he never returned to it, and the 'useful applications' quite obviously escaped him. It was only Kant who saw them, and who could therefore tell what was of permanent value in Wright's book.

It is impossible to overrate the influence which British science and philosophy exerted on Kant's development. Throughout his life he faithfully followed Newton's doctrines, and when writing his *Universal Theory of Celestial Evolution* he prefaced it by an 'Outline of the most necessary principles of Newton's Natural Philosophy' required for the understanding of his own work. His original philosophical period started with the reading of Hume, who, in his own words, 'awakened him from his dogmatic slumber.' In

Wright we meet another Englishman who decisively helped Kant to formulate his own ideas, a fact which is all the more noteworthy if we remember that Wright left no mark at all on the development of astronomy in his native land.

It is an old and very obvious truth: *pro captu lectoris habent sua fata libelli.* The fate of a book is determined by the capacity of the reader; it cannot, however, have happened many times that one reader alone—and in a foreign country at that—saw a spark of genius amid much indifferent writing, and by adopting and developing the one brilliant idea saved the memory of the author from oblivion.

LITERATURE ON THOMAS WRIGHT

[1] 'A Sketch of the Character of Mr. Thomas Wright, late of Byer's Green Lodge, in the County of Durham,' *Gentleman's Magazine*, **63**, 6 and 126, 1793. The author of this anonymous article had been a friend of Wright and could base his statements on personal observations and Wright's own notebooks. This is the only original source of information on Wright's life; paragraphs concerning him in biographical dictionaries and topographical works (on Darlington, Bishop Auckland, the county of Durham, etc.) are mostly copied *verbatim* from it. Wright's portrait prefixed to the article is similar to the engraving reproduced here (see figure 3), but much cruder.

[2] 'Mr. Wright's Description of his Villa at Byer's Green,' *Gentleman's Magazine*, **63**, 213, 1793. A very characteristic letter by Wright to a friend, published as an appendix to the above article.

An appreciation of Wright's scientific achievements and of his influence on Kant is to be found in the following papers:

[3] De Morgan. 'An Account of the Speculations of Thomas Wright of Durham,' *Philosophical Magazine* (3), **32**, 241, 1848.

[4] Sampson, R. A. 'Thomas Wright, the Durham Astronomer,' *Proceedings of the Society of Antiquaries of Newcastle-upon-Tyne*, **8**, Jan. 1895 to Dec. 1896.

[5] Hastie, W. 'Kant's Cosmogony,' James Maclehose and Sons, Glasgow, 1900.

[6] Paneth, F. A. 'Thomas Wright of Durham and Immanuel Kant,' *Durham University Journal*, N.S., **2**, 111, 1941; reprinted, somewhat abbreviated, in *The Observatory*, **64**, 71, 1941.

Copious abstracts from Wright's biography and books are contained in:

[7] Gushee, Vera. 'Thomas Wright of Durham, Astronomer,' *Isis*, **33**, 197, 1941. The genuineness of the portrait added seems very doubtful.

BOOKS PUBLISHED BY THOMAS WRIGHT

Pannauticon, 1734. According to Wright's biographer, a treatise on navigation sponsored by the Navy and published by subscription. Strangely enough, no copy and not even a record of this book could be traced in any library.

The Universal Vicissitude of Seasons, 1737, seems to exist only in the one copy which, since 1948, is in possession of the Durham University Library. Diagrams and ornaments are drawn and coloured by hand, so that this curious work, in spite of the use of copper plates, is nearer to a manuscript than to a print.

The Use of the Globes, 1740. A booklet written at the request of John Senex, F.R.S., to serve as an instruction for the use of his terrestrial and celestial globes. Now rare.

Clavis Coelestis, being the Explication of a Diagram entituled a Synopsis of the Universe: or, the Visible World Epitomised, 1742. A popular introduction to astronomy, with three large plates, each containing several figures. These plates are of such an awkward size that in some copies of the book they have been cut into quarto sheets; in others they are badly damaged or even missing.

Louthiana, 1748. A description of the antiquities in the Irish county of Louth. The illustrations, some of them signed by Wright, show both his technical skill and his limitations as an artist. Copies in many libraries.

An Original Theory, or New Hypothesis of the Universe, 1750. Wright's chief publication, the subject of the present article. Four copies in Durham libraries; a few others elsewhere.

The Longitude Discover'd without use of Graduated Instruments, 1773. According to Miss Gushee a copy of this work is preserved in the New York Public Library.

In the custody of the British Museum are two of Wright's manuscripts: the 'Journal,' on which the biography in the *Gentleman's Magazine* is largely based, and 'Observations on . . . Remains of Antiquity . . . taken on a tour through England' (British Museum Add. MSS. 15627 and 15628).

The Royal Society possesses a few letters by Thomas Wright on astronomical and archaeological subjects, and the Royal Astronomical Society a calligraphic letter, 'To their Excellencis the Lords Justices of the Kingdom of Ireland,' in which Wright proposes to draw an accurate map of the ports, rocks, etc., of the shore of Ireland in the interest of navigation.

Colour in the day sky

JAMES PATON

'. . . there is not a moment of any day of our lives when nature is not producing scene after scene, picture after picture, glory after glory, and working still upon such exquisite and constant principles of the most perfect beauty. . . .' (Ruskin, *Modern Painters*). This article explains some of the optical phenomena which lend colour and splendour to the day sky.

While the colour of the cloudless day sky is predominantly blue, any colour or combination of colours of the visible spectrum may appear if prevailing conditions are suitable. Especially near dawn and sunset, portions of the sky may display tints ranging from vivid purple and dark red, through orange and yellow, to green and violet (though the eye is not strongly sensitive to violet). When scattered rain clouds are present, there may appear a concentration of spectral colours in the rainbow; when the tenuous sheet of ice crystals composing the cirro-stratus cloud extends in front of the sun, the coloured rings and arcs of the halo may be visible; when the clouds consist of particles of the requisite size and concentration, those near the sun may show the iridescent sheen characteristic of a corona. If, however, the canopy of cloud becomes thick and unbroken, the intensity of the light is so reduced that both sky and landscape assume a uniform greyness.

It was not until the latter part of the nineteenth century that a satisfactory explanation of the cause of the blue of the sky was forthcoming. Brücke, and later Tyndall, showed experimentally that a suspension of small particles (through which objects can be seen clearly) appears blue when illuminated by white light, and Lord Rayleigh demonstrated theoretically that light scattered by atmospheric molecules 'would suffice to give us a blue sky not so very greatly darker than that actually enjoyed.' In fact, he showed that the intensity of light scattered by a single particle of dimensions small compared with the wavelength λ of light varies inversely as λ^4, so that sky light, being scattered sunlight, contains all the spectral colours, but those of the shorter wavelengths, violet and blue, appear in by far the greatest intensity (top curve, figure 1, p. 131). The sun is most markedly red at dawn and sunset, because then its light is most effectively depleted of the shorter wavelengths by its passage through the maximum thickness of air.

When a shadow due to an extensive cloud sheet is cast on the path of light coming from clear sky near the horizon (figure 2), the distribution of light intensity among the different colours may be so altered by further scattering as to cause the distant sky to appear orange or, less frequently, green. The curves of figure 1 show that as the distance OA increases, the proportionally greater scattering of the shorter wavelengths causes the maximum to move from blue to green and eventually to orange, the last requiring a path of about 30 miles. This unusual coloration may develop whenever, as for example at twilight, light from a portion of the sky traverses a region in shadow. The light that first returns to the sky at the horizon after a total eclipse of the sun is orange in colour.

While small particles scatter preferentially the violet and blue with an intensity which is almost independent of direction, larger grains, e.g. larger dust particles and water drops, scatter all colours equally but almost entirely in directions close to that of the incident light (figure 3). The latter fact explains the increase in brightness and whiteness of the sky towards the sun. It is at an angle of about 90° from the sun that the sky is darkest and most blue, for only the smallest particles—mainly molecules—are effective in directing light in this direction: hence the deep blue of a clear zenithal sky at dawn and at sunset (plate 12). The sky becomes again whiter and brighter towards the horizon (plates 7 and 8), partly because there is a greater concentration of larger particles close to the earth's surface, and partly because of the greater optical thickness of the air in this direction. For, although each distant molecule scatters the blue and violet preferentially, these are just the colours which are most strongly depleted during the passage to the observer, so the composition steadily approaches that of white light (figure 1). This whiteness along the horizon changes to orange at sunset.

While the presence of fine dust adds to the blue

1

2

3

4

PLATES 1–4 – *The eastern sky around sunset:* (1) *At sunset;* (2) *seven minutes after sunset;* (3) 15 *minutes after sunset;* (4) 21 *minutes after sunset. Observe the ascending earth shadow, the twilight arch, and the anticrepuscular rays (formed by clouds on the western horizon) in the counter twilight. Clouds on the eastern horizon (plate* 1) *remain bright after the foreground has become dark.*

PLATE 5 – *The effect of large particles in suspension in the atmosphere. Glen Lednock, Perthshire, in clear conditions.*

PLATE 6 – *The same view in mist.*

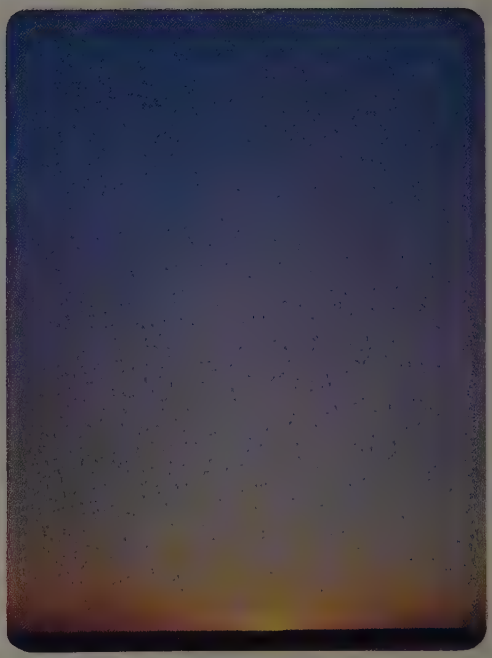
PLATE 7 – *Light and shade in cumulus clouds. Glen Feshie, Inverness-shire.*

PLATE 8 – *The extension of the blue of the sky in front of distant hills. Strathearn, Perthshire.*

PLATE 9 – '*The sun drawing water.*' *Crepuscular rays.*

PLATE 10 – *Bishop's Ring. Photograph taken in Canada some days after a volcanic eruption in Iceland.*

11



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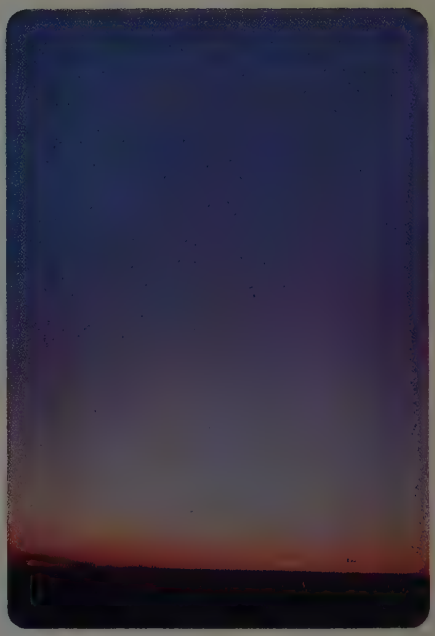

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PLATES 11–14 – *The western sky at sunset. The afterglow:* (11) *One minute before sunset;* (12) *sunset;* (13) 18 *minutes after sunset;* (14) 30 *minutes after sunset.*

of the sky and enhances the red of the sunset, as in industrial areas and after volcanic eruptions (plate 10), larger particles whiten (or, in the case of smoke particles, add their own colour to) the blue, their effect being readily observed in the marked deepening of the blueness after a heavy shower has carried them down to earth. When present in quantity in the lower atmosphere, dust grains or water droplets make visible the straight paths of rays that form the boundary of cloud or mountain shadows (plate 9). Although, of course, the rays are parallel, they appear by perspective to converge, like the ribs of a fan, to the sun or the anti-solar point (plates 1, 2, 3 and 4), and give the impression of 'the sun drawing water.' Being most frequently associated with twilight, they have become known as crepuscular rays, but they may be seen in suitable conditions at any time of day.

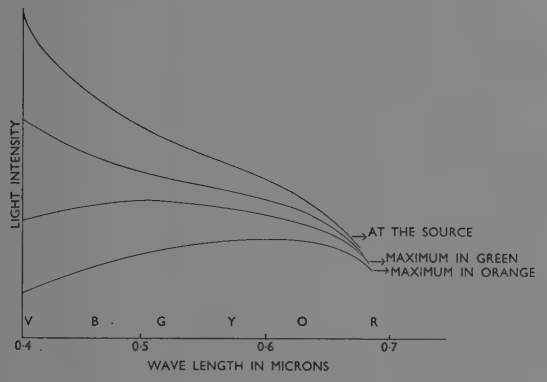


FIGURE 1 – *The change in the composition of light scattered by a small volume of air during transmission through increasing lengths of air path. The top curve shows the composition near the scattering element. The lower curves show the effect of further scattering with increasing distance from the source. The lowest curve would represent roughly the effect of passage through a path of about 30 miles in length.*

The suspension of water droplets that constitutes mist causes objects seen through it to appear whiter (plates 5 and 6), the mist itself showing up most clearly in directions close to that of the sun (figure 3).

The water drops in a cumulus cloud are so densely packed that its surface is an almost perfect reflector; where lit by direct sunlight it is a dazzling white, while parts in shadow are dark grey. A developing cumulus thus appears rocklike in form, with striking contrasts in light and shade (plate 7).

In clear conditions, when large particles are absent, the blue of the sky may be seen to descend in front of distant hills (plate 8). Scattering by the atmosphere between the observer and the hills adds blue to the light coming from the dark background, and provides a means of estimating distances by comparing the intensities of the blueness of distant horizons. There is a complementary effect, which is not so readily observed. In conditions of excellent visibility, snow-capped hills and cumulus clouds become more yellow the greater their distance. Here, the strong light from the bright background reaches the observer depleted of violet and blue, but this net loss of blue is small compared with the total intensity. When the distant background is dark, a very large proportion of the light that reaches the observer is directed to him by atmospheric scattering.

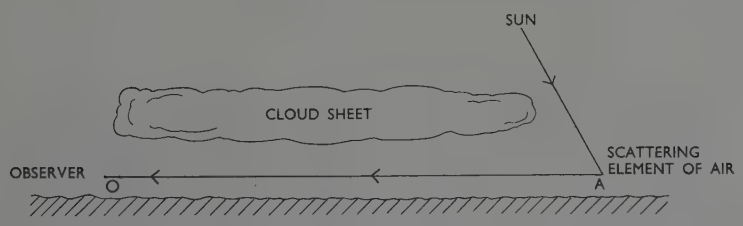


FIGURE 2 – *The passage of light from clear sky at the horizon to an observer across an unilluminated (shaded by a cloud) portion of the atmosphere.*

The geometry of the rainbow was first given by Descartes, who showed that when a ray of sunlight enters a raindrop and is reflected at the back surface, the direction of the emergent light is confined between the direction of the ray that falls normally on the drop and that of the ray of minimum deviation. Actually, this once-reflected light is so

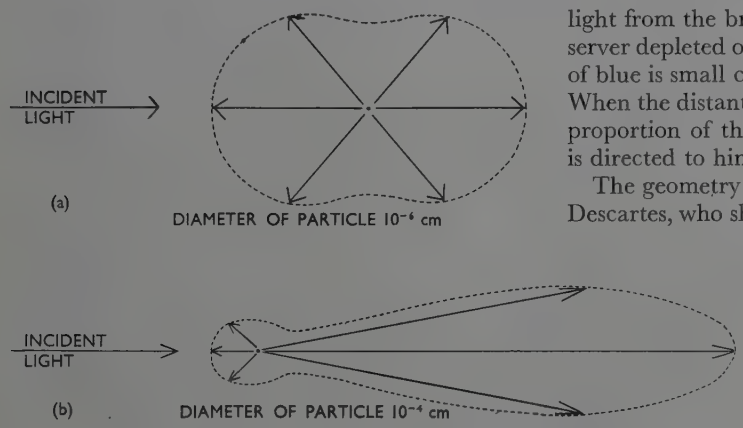


FIGURE 3 – *The variation with direction of the intensity of scattered light.*

PLATE 15 – *Primary and secondary rainbows. Note the darker area between the bows.*

PLATE 16 – *Halo. The 22° ring.*

(Plates from Kodachrome transparencies by John F. Steljes.)

strongly concentrated in the latter direction that an observer in a position between an unobscured sun and a rain shower sees a bow (the primary bow), part of a circle of angular radius 42° whose centre lies on the line from his eye to the antisolar point. Because light that has been once reflected within a raindrop can reach the observer only from the part of the sky that lies below the bow, the region above the bow is generally darker than that below, but this contrast is often masked by sunlight reflected from the cloud background.

Light which suffers two reflections within the raindrop produces in the same way a bow of radius 51° (the secondary bow) with the spectral colours reversed. Twice-reflected light can reach the observer only from the sky above the bow, so that, if reflection by the cloud background is weak, the region between the red summit of the primary and red base of the secondary bow is markedly darker than the rest of the sky (plate 15). The supernumerary bows that appear outside the violet, below the primary and above the secondary bow, are interference bands, whose width and spacing are determined by the diameter of the raindrops. The rainbow colours become more vivid as the size of the raindrops increases.

The hexagonal ice crystals of cirrus and cirrostratus clouds provide a wide variety of possible paths for sunlight, and so may cause concentrations of the light in the rings, arcs, and parhelia that are classed as halo phenomena. Some, like the small 22° ring, are of common occurrence; others are rarely seen. Since a columnar hexagonal crystal refracts the light as a prism with refracting angle 60°, a minimum deviation of about 22° occurs at symmetrical passage, the refractive index of ice for yellow light being 1·31. As each crystal rotates towards and beyond the position giving minimum deviation, the direction of the emergent light changes only very slowly, so that there is always a larger number of crystals directing light around this direction than in others. Thus, in a haphazard arrangement of crystals, light is concentrated in the direction of the ray of minimum deviation, that is, in directions at 22° from the direction of the sun, to form a ring of 22° radius with a red inner border, for red suffers least deviation. Mainly because of the variations in deviation caused by tilting of the crystals, other colours almost disappear by mixing, and there is usually merely pale light beyond the red border (plate 16). As no refracted light reaches the observer from within the ring, the region just inside the ring is darker than the region outside it, but of course scattered sunlight, strong near the sun, may completely mask this effect.

Diffraction by the drops in a cloud veil covering the sun or moon is the cause of the formation of the reddish-brown-edged aureole, the corona, whose diameter and colour distribution depend on the size of the droplets. The iridescence that is sometimes seen on clouds at distances as great as 30° from the sun is almost certainly a portion of a corona produced by an assembly of minute cloud particles of uniform size. Occasionally, after the occurrence of a volcanic eruption, the sun may be continuously surrounded by a reddish-brown aureole—the 'Bishop's Ring,' so called because it was first observed after the Krakatoa (1883) eruption by the Bishop of Honolulu (plate 10).

Sunrise and sunset provide the greatest splendour of sky colour. In favourable conditions at sunset the earth's shadow, the blue-grey twilight arch, rises in the east carrying above it the coloured horizontal bands of the counter-twilight (plates 1, 2, 3, and 4): purple, crimson, orange, yellow, green, blue in order upwards, to merge into the diffuse illumination caused by reflection of the stronger light in the west. About forty minutes after sunset, the boundary line of the earth's shadow has become indistinguishable, and the counter twilight has usually vanished. The explanation of the bands of the counter twilight lies in the fact that the light illuminating the eastern sky becomes progressively more red, by scattering, the lower its path through the atmosphere. In the west, the yellowish, sometimes rosy glow, that has encircled the sun (see figure 3) as it approaches the horizon, remains visible in its upper portion for almost half an hour after sunset (plates 11, 12, 13, and 14), slowly changing in colour through pink to bluish white. While this gradually vanishes at about half an hour after sunset, there may appear for a short time the brilliant purple glow that becomes so striking when it illuminates the western sides of tall buildings. This may be due to the presence at heights of 10–20 km of a layer of fine dust, whose lower portions are bathed in red light while the upper parts receive light which, having traversed a region of more rarefied air, still contains much blue.

A comprehensive and excellent account of atmospheric optical phenomena will be found in Minnaert's *Light and Colour in the Open Air*. G. Bell and Sons Limited, London. 1940.

Parasites and war

GEOFFREY LAPAGE

The most cursory study of military history reveals that by far the greatest danger is not the armament of the enemy, but parasites which profit by the disorder of war to break the bounds which barely restrain them in normal times. In almost all military campaigns, from the earliest times up to the present day, such diseases as malaria, typhus, dysentery, and trichiniasis have exacted a heavy toll from both the troops and the populations of the battle areas.

Parasites of all kinds have throughout history exerted a powerful influence upon war. In the tropics especially, and in all the warmer countries, military commanders must reckon with their power to curtail or defeat the soldier's plans. Most people, no doubt, will be well aware of this fact. They will have read about, or heard of, the ravages of such diseases as typhoid fever and bacillary dysentery, which are caused by bacteria. Less well known is the fact that some animal parasites can exert as great an influence upon war as that exerted by bacteria and viruses.

Among the parasitic animals which attack man, perhaps the malarial parasites are the most powerful. Well known even in Hippocratic times, and probably much earlier, malaria caused, and still causes, so much illness that it is regarded by some experts as the worst of all human diseases.

The chronic ill-health that malaria causes, the large numbers of people killed by it, and its ability gradually to destroy the virility of whole nations, are well established in a vast literature. It has been suggested, for instance, that one of the factors which caused the degeneration of the Greek nation and their surrender to the Romans was the malaria that became prevalent in their country, and that periodic cycles of malaria in the Campagna coincided with fluctuations in the power of Rome and with its decline and fall. Widely distributed as malaria now is over the tropical and subtropical areas of the world, and in many temperate zones also, it is only nowadays that it is yielding to measures of control devised by modern science. These measures not only attack the parasites in the human body, but make it possible to eradicate malaria-carrying mosquitos from large areas of difficult country. The great pioneer feat which eradicated the mosquito *Anopheles gambiae* from Brazil has since been repeated in Egypt, and malaria-carrying mosquitos have been successfully attacked in Cyprus and elsewhere. There seems to be no doubt that we are well on the way to the control of this devastating disease, especially since the discovery of Paludrine (see ENDEAVOUR, 5, 65, 1946).

Although the world may be freed in the future from the menace of malaria, there is no doubt that until very recent times it has been a scourge providing a primary problem for military commanders operating in areas in which it is endemic. It has upset strategies and caused defeats, and, when it has attacked both sides in battle, all fighting has been stopped. Numerous instances could be cited to support this statement, but a few, taken from recent wars, must suffice. During the first world war, when the allies were operating in Macedonia, both they and the Germans suffered heavy losses caused by malaria, as readers who served in that area will remember. In 1916, about a quarter of the British Macedonian force of some 123,000 men had to be taken into hospital to be treated for malaria, and the French troops suffered equally severely. In 1917 and 1918, almost half the British force was put out of action by the disease. The German armies also suffered to much the same degree, and military operations were made impossible. In 1916, the East African expeditionary force of about 58,000 men was practically immobilized by malaria, some 50,000 of them being in hospital during that year. In 1917, 72,000 men were taken into hospital with malaria and 499 men died of it. In Iraq also, malaria reduced the effective forces considerably.

During the second world war, malaria remained a serious peril to the allied armies. Dr Hamilton Fairley, writing in *The Fight against Disease*, the organ of the Research Defence Society (1947), tells us that casualties caused by malaria in the south-west Pacific area during four months in late 1942 and early 1943 amounted to about 90 per cent. of the forces employed. Incidentally, he quotes figures which show that, during the early

campaign against the Japanese in 1942–3, casualties due to disease were 5–30 times as numerous as those incurred in battle. This incidence of disease was experienced alike by British and Indian troops in Burma, by United States troops at Bataan and Guadalcanal, and by Australian troops in New Guinea and New Britain. At Bataan, about 85 per cent. of the men of each United States regiment had malaria, and some experts believe that the reverse of these troops was due as much to malaria as to any other cause. In addition to malaria, troops in this area suffered from bacillary dysentery, dengue fever, scrub-typhus, and various skin diseases, but the importance of malaria is shown by the fact that, of the medical casualties suffered by the Australian forces in New Guinea between September 1943 and February 1944, 60·8 per cent. were due to malaria. Although the Japanese forces also suffered severely, the menace of malaria to the British and their allies was very grave, and the researches described by Dr Fairley were given high priority. The result of this work was that the threat of malaria was controlled.

The malarial parasites belong to the group of single-celled animals called Protozoa, among which is also the amoeba (*Entamoeba histolytica*), which causes amoebic dysentery. This disease, which must be distinguished from the bacillary dysentery caused by bacteria, has also been a potent enemy of armed forces. Human beings are infected by the minute cysts of this amoeba, which pass out in the solid excreta and may get directly into the water supplies or food, or may be carried there by flies and other means. Efficient sanitation will therefore do much to eliminate this disease. Lack of effective sanitary measures led to a prevalence of amoebic dysentery, and probably other parasitic diseases, among the Axis troops in Egypt during the recent war. Certainly some of these troops left behind them, after the battle of El-Alamein, a legacy of insanitation which makes one wonder whether one of the causes of their defeat was not the dysentery from which they suffered. This state of things was the more remarkable because the German *Afrika Korps* was instructed in the risks of parasitic diseases with characteristic thoroughness, as part of intensive training for war in hot countries. In south-east Asia, the incidence of amoebic dysentery among allied troops was about 12 per cent., but in the south-west Pacific it was lower.

One reason why malarial parasites can exert such devastating effects upon man is the fact that, once they have been injected into him by a mosquito, they can multiply inside his body, as bacteria do. They also multiply inside the body of the mosquito which injects them into man. One mosquito bite may thus put into human blood enough malarial parasites to cause—when they multiply—a heavy infection which can overcome the defences of the human body comparatively rapidly. The parasitic roundworms, on the other hand, some of which are serious dangers to military operations, cannot multiply in this way, so that they exert their effects more slowly. If, however, enough roundworms get into the human body, their effects can be serious. Among the species of roundworms which have affected troops in action, the pork trichina worm (*Trichinella spiralis*), the large roundworm of the small intestine (*Ascaris lumbricoides*), and the filarial roundworms are probably the most important.

Trichinella spiralis, which causes the disease called trichiniasis, is usually acquired by man when he eats raw pork containing the larvae of this worm, or pork that has not been cooked sufficiently to kill them. On active service it may not be possible to cook pork effectively, or the soldiers may prefer it uncooked. A small German commando unit, for instance, operating on the Polish frontier during the 1939–45 war, halted for the night and appropriated a pig from a nearby farm. The men ate the meat raw, partly because they were very hungry, and partly because they could not advertise their presence by lighting a fire for cooking. Unfortunately for them, the pig's muscles were infected with the trichina worm, which is not uncommon in this part of Europe. The result was that they were all put out of action by trichiniasis.

More serious from the point of view of the enemy was the provision, for a German battalion operating in Norway, of a meal of raw or insufficiently cooked pork. Most of the battalion got trichiniasis and became casualties. Many of them sent presents of the meat to their friends or relatives in Germany, who also became infected. The German authorities subsequently had to deal with many cases of the disease among civilians.

Less serious, but serious enough, were the effects of the human pinworm (*Enterobius vermicularis*), which is a well-known parasite of children in all parts of the world. This worm is transmitted from one person to another by means of its eggs, which are laid by the female worm around the vent. The female pinworm comes out through the vent during the night to do this, and her

emergence may cause severe itching, restlessness, and loss of sleep. German munition workers, herded into deep air-raid shelters and already severely worried by allied bombing, became infected with *Enterobius*, and the discomfort and insomnia which it caused became so severe that the output of munitions was affected. Special researches were therefore initiated to find a means of combating *Enterobius* and its effects. The incidence of threadworm among the allied forces, especially among certain sections of them operating at home and congregated in confined spaces, was also considerable.

The Guinea worm, which is probably identical with the 'fiery serpent' mentioned in the Bible as a plague of the Israelites (Numbers, Chap. 21, v. 6), is a roundworm which crippled an appreciable number of West African troops so severely that they had to be invalided out of the service. In the Far East, filarial roundworms were responsible for the disablement of troops by giving them the two diseases known as onchocerciasis and filariasis. The worms which cause onchocerciasis are transmitted by mango flies. They become enclosed in hard nodules under the skin and elsewhere, but the nodules do not usually cause serious trouble. The worms which cause filariasis, however, which are transmitted to man by mosquitos, may, after a number of years, cause the dreaded enlargement and thickening of the lower limbs and other parts of the body called elephantiasis. The worms require treatment, therefore, not so much because they incapacitate the soldier immediately, as because they have slowly progressive results and create, in the infected persons, reservoirs from which mosquitos may transmit the disease to others. There is also the risk that infected persons, returning to their home countries, may bring the infection with them, and may therefore establish the disease in parts of the world in which it was not formerly present. This can, of course, happen only in areas in which the species of mosquitos capable of transmitting the disease are to be found.

A similar risk is created by the return home of people infected with malaria and other parasitic animals. Mosquitos capable of transmitting malaria exist in England, for instance, especially along the coast from East Anglia to the Isle of Wight, and, after the first world war, the return of troops infected with malaria caused outbreaks of the disease in England. Similar legacies of wartime malarial infection occurred in Holland and other parts of Europe. A repetition of such outbreaks after the second world war was prevented by the energetic measures that were taken.

The parasitic worms called flukes are, on the whole, less injurious to troops, but the blood-flukes (e.g. *Bilharzia*), whose young develop in water snails and infect man either through his mouth or by penetrating the skin, can cause the commanders of armies a good deal of anxiety. The men must be instructed not to drink or wash, or even shave, in water likely to contain these young flukes, unless it has first been boiled or treated with chemical substances that will kill the parasites. Special precautions have therefore to be taken, and the work of the army authorities is much increased.

All the parasitic animals so far considered are species which live inside the body of man, and are themselves the causes of the diseases mentioned. There remain for consideration two species of parasites which do not themselves cause disease, but can transmit diseases which may rapidly reduce armies to impotence. These are the human lice which transmit to man the cause of epidemic typhus or jail-fever, and the larvae of the mite which transmits the cause of scrub-typhus. Both epidemic typhus and scrub-typhus are caused, not by the lice or mites which respectively transmit them, but by organisms which stand somewhere between the bacteria and the viruses and belong to the genus *Rickettsia*. Both diseases belong to the typhus group of fevers caused by *Rickettsia*, and must be distinguished from the typhoid group of fevers, which are caused by bacteria.

Epidemic typhus has always been a scourge of mankind. Probably some of the pestilences recorded in ancient times were epidemic typhus, which attacks human populations especially when their health is weakened by famine, or by the mass migrations caused by political upheavals or by war. It used to be very prevalent in ill-kept and insanitary prisons and thus acquired the name of jail-fever. The history of war is full of references to it. It must be distinguished from endemic typhus fever, which is a similar but milder disease caused by a different species of *Rickettsia*. Endemic typhus is limited to certain parts of the world and does not become epidemic. Usually it is passed from rats to man by species of rat fleas and rat lice, but human lice and rat fleas can transmit it from man to man.

Epidemic typhus, on the other hand, is transmitted from man to man by human head and body lice (*Pediculus humanus*), and for this reason it may spread rapidly to large numbers of people. It attacked Spanish soldiers during their conquest

of Granada, and spread all over central Europe in the seventeenth century at the time of the Thirty Years' War. It has been a feature of most European wars. One of the most severe modern epidemics of it occurred in Serbia in 1915. When the epidemic was at its worst, as many as 2500 people were admitted to military hospitals every day, and about three times as many cases were known among civilians. From 30 to 70 per cent. of the infected persons died, and there were more than 150,000 deaths in six months. Poland also was at this time a centre of the disease. In 1918, after the war, a severe epidemic broke out in Rumania, causing 800,000 deaths, and in Russia, where some five million people were infected.

When the Italians attacked Abyssinia they benefited greatly by the fact that they kept themselves free from lice while the Abyssinians did not. Typhus was therefore completely absent from the Italian army, whereas the Abyssinians had about 20,000 cases in 1935. During the 1939–45 war, epidemic typhus broke out in Naples when the Germans were driven out of that part of Italy. The health of the Italian population of the city had been undermined by malnutrition and the destruction by the Germans of the sanitary services and water supplies, so that they succumbed readily to the disease. The vigorous use of pyrethrum, and of D.D.T., the effects of which were at that time only newly discovered, killed the lice and checked the outbreak. It was thus demonstrated that D.D.T., whose insecticidal properties had remained unknown for many years, could with proper use remove from human communities one of their most devastating scourges.

Scrub-typhus, which is better called mite-typhus (because this name distinguishes it from the louse-borne epidemic typhus), is a disease of Japan, Burma, and neighbouring areas. It is caused by a species of *Rickettsia* transmitted to man by the larvae of certain mites related to the 'harvesters' which annoy people in some parts of England and elsewhere. The disease has been known for a thousand years or more, and has been given various names, among which are tsutsugamushi disease, Japanese river fever, scrub-typhus, and mite-typhus. Rats, field voles, and probably other animals are reservoirs of the *Rickettsias* from which mites transmit them to man. During the recent war this disease became such a serious menace to our troops in the Burma area that strenuous efforts were made to control it. In order to try to prepare a vaccine against it, cotton rats were flown from America to England, and a well-equipped laboratory was built in record time to accommodate the team of specialists who made the vaccine. This brilliant team, who risked their lives—two of them died—to do a piece of work which was one of the outstanding feats of the war, had hardly produced their vaccine when the Japanese capitulated. Meanwhile, Australian workers, using human volunteers found that butyl phthalate was an effective means of dealing with the mites which transmit the cause of the disease. Rubbed into socks, canvas anklets and gaiters, trousers, and shirts, it killed the mites, and its use reduced the incidence of mite-typhus in New Guinea from 36 to 1 per 1000 per annum.

It is not possible on this occasion to consider other aspects of the relationships between parasitic animals and war. An interesting volume could be written on the part played by parasites, not so much in the destruction or immobilization of armies, as in causing the political changes which have led to wars. The spread of parasites, or of animals which transmit them, by the rapid means of transport used in both peace and war—aeroplanes, land vehicles, and ships—is another very important aspect of the subject which cannot be dealt with here. Both are chapters in the interesting general history of the effects of parasites upon the development of human civilization. If parasites can hamper or stop wars, they can also severely hamper human industries, especially in tropical countries. Some of the species which attack domesticated animals and certain crops, such as potato, wheat, barley, sugar-beet, and others, can greatly reduce the production of essential world food supplies. Clearly it is true that, if parasites are able to do what no other agency can do, namely, to stop wars, they can do this only by destroying or immobilizing the fighting men. They may therefore be more serious enemies than the human adversaries against which armies strive. Military necessity has spurred men on to battle with them with an energy and an ingenuity which their peace-time menace to our industries and food supplies has not yet evoked. During the 1939–45 war especially, necessity forced us to a richness of invention which has made that distressing period one of the greatest in the annals of science. If so much benefit to the human race has come from the parasite's challenge to our ability to make war, how much more might come to us if we took up, with equal energy and speed, its challenge to our food production (see ENDEAVOUR, **7**, 27, 1948) and industrial capacity.

The cultivation of algae

E. G. PRINGSHEIM

The growing of pure algal cultures no longer presents the great difficulties formerly encountered, owing to recent improvements in technique. On the one hand it has resulted in new advances in plant physiology, especially in the study of photosynthesis, in ecology, and in the development of new forms of bio-assay. On the other hand, the large-scale cultivation of algae, although still in its infancy, may assume considerable practical importance—for instance, as a source of food. Dr Pringsheim explains the value of maintaining pure algal strains.

The culture of algae dates from some seventy years ago. It was not an individual contribution to botany, but developed from various sources. Observation of material kept in the laboratory without special apparatus, the use of nutrient solutions as employed in the study of higher plants, and the application of the methods of bacteriology, all had their share in the evolution of a technique for obtaining a healthy growth of algae under artificial conditions.

The most important step was the isolation of the species to be cultivated, culminating in the elimination of all other organisms, so that pure cultures resulted. This isolation is valuable, inasmuch as it brings us nearer to a complete control of conditions. Pure cultures are, however, neither always necessary for achieving valuable results, nor an end in themselves. In order to reap every possible benefit one has to employ synthetic, completely defined media, and to follow with the help of analytical methods their alteration by the metabolism of the growing algae.

Until recently, cultures of algae were believed to be useful and necessary for physiological investigations only. Even so, the application of bacteriological methods and media, without sufficient adaptation to the needs of the algae, entailed some reverses, since it not only excluded the vast majority of algae, but forced unnatural conditions even on those which could be grown. The field algologist could not make much use of such a technique, which distorted the shape of the organisms, and he therefore discarded cultivation altogether. The methods, imitating those successfully used with bacteria and fungi, combined in one manipulation the provision of food and the isolation of single individuals by using nutrient agar media, so that the individuals could multiply to form homogeneous colonies. The isolation of algae is, however, not as easy as that of most bacteria and yeasts. In the material used for inoculation, the number of algae is much smaller than that of contaminating organisms, and the agar used for fixing the individual algae in their places, and separating them from others, also favours these contaminants. Many are apt to spread over the substratum, frequently frustrating the efforts at isolation.

It was therefore necessary to divide the manipulation into two steps: first, mechanical isolation, and then the transfer into conditions favourable for multiplication. While formerly those algae were isolated which grew best in the medium—and only when one species predominated from the beginning was it possible to proceed more systematically—we now begin by choosing under the microscope the species which we intend to grow, and transfer it into a sterile fluid. In the majority of cases, the best way to isolate an alga is to suck it into a glass capillary, and then to blow it out, by means of a rubber cap. With this technique, it has become possible to analyse a complicated mixture of species by transferring each of them into separate culture vessels.

Full advantage of this mechanical separation is, of course, gained only if the isolated individuals are given suitable conditions for multiplication, and for this purpose a consideration of their ecological requirements is needed. Species from deep lakes, and other waters with a low concentration of nutrient substances, are best grown in very dilute solutions of inorganic salts containing all the essential chemical elements. Those from shallow, and more or less polluted, waters need a greater amount of nutrient substances than can be dissolved in an aqueous medium. In the natural habitat of such algae these substances are mainly supplied from the underlying deposits of mud. In cultures they can be provided by adding a little soil to replace the partly organic substances contained in mud. Previous heating destroys the competing micro-organisms contained in every

soil, but no autoclaving is allowable, for this greatly impairs the suitability for growth. Many variations of the technique are possible, imitating the natural conditions, and almost all algae can now be grown in culture.

The result of such culture experiments, if successful, is a plentiful and healthy homogeneous algal material from which further cultures, completely free of other organisms, can be derived. We are not yet able to satisfy in pure culture the requirements of every algal species in respect of *p*H, chemical elements, and vitamin requirements. There are many species which thrive in soil-water cultures but cannot yet be grown in bacteria-free media, so that we are only at the beginning of a still wider development in the cultivation of algae.

In nature, biological communities are always mixed, and this renders unavoidable the interaction of various organisms. It will therefore never be possible to draw a true ecological picture by concentrating on a restricted number of taxonomic groups—for instance, bacteria and fungi—leaving algae and protozoa out of consideration. It is just because of this necessity to fill the gaps, in order to come nearer to a real general microbiology based on ecological knowledge, that the methods of growing algae (and also flagellates and ciliates) have yet to be improved.

The programme of culture research on algae is theoretical as well as practical. A few of the tasks will be indicated. Some are general problems which can best be tackled by using algae, others are problems related to algae specifically. If, for instance, the osmotic organization of plant cells is to be investigated one may, among others, consider the large cells of *Hydrodictyon*. If, however, the formation of the swarmers of *Hydrodictyon*, and the way these arrange themselves to form daughter nets, is to be studied, no other material can be used. In both cases it is most useful to have the alga available in a healthy state throughout the year. Too often it has happened in the past that such investigations came to a premature end because the material was no longer to hand.

Algal cultures are already widely used in Britain for teaching purposes. The species generally required are kept constantly in stock in good condition. Universities and schools soon grasped the advantage of having available at short notice most of the forms they required.

An outstanding example of the use of algae in research is in the study of photosynthesis, a field of the greatest importance because the chlorophyll system of plants is practically the only apparatus for supplying the organic substances essential to life. At last, too, chemists and physicists have joined physiologists in research on photosynthesis, and the progress already achieved is immense. Algae are the objects of choice for this work, as they provide a homogeneous and easily handled cell-material. Again, algae are not only, for many purposes, better suited than other green plants, but the peculiar photosynthesis of certain algae attracts the attention of physiologists. While the pigment system of most green algae is the same as that of flowering plants, ferns, and mosses, there are also groups with different pigments—for instance, the red and brown algae. The results obtained with these various groups show certain differences in behaviour which have thrown new light on basic problems.

For investigating these pigments and their physiological properties, one had until recently to rely on occasional natural mass production. Harvesting was not easy, and the admixture of other algae with different pigments was unavoidable. Mass cultures, first of modest dimensions, but now already on a large scale, provide the answer to these difficulties. The cultures will also make available other contents of algal cells—for instance, peculiar (possibly precious) oils, little-known sugars and polysaccharides, and new vitamins. Optimists even expect a valuable contribution to our food resources, and believe that such schemes could soon be practicable and economical.

In comparing the quantity of organic substances photosynthesized by traditional crops and algae respectively, and leaving apart the food value for human beings and livestock, one comes to figures of the same order of magnitude. In both instances only up to 1 per cent. of the light-energy is utilized, so that the scope for improvement is considerable.

In any case, production is generally limited not so much by the inner nature of the photosynthetic system as by external factors. It appears that a warmer and sunnier climate than that of Britain, as found for instance in the West Indies, would be essential for success. On the other hand, carbon dioxide fertilization, from which much may be expected, is feasible only in industrial areas where this gas is produced in excess of other needs. Artificial illumination is under present technical conditions largely restricted to experimental purposes, and is expensive.

In order to make the production of vast masses of small algae really feasible, much more knowledge of their nutritional requirements for profuse

multiplication is needed; this could then be used to apply an improved technique on an ever increasing scale. Chemicals which are useful and cheap enough for experiments up to a certain size may not be available, pure, in sufficient quantity for mass production, and impure materials may be toxic. Many unforeseen difficulties are certain to arise if no proper preparatory study has been undertaken.

The difficulties which can be foreseen are: invasion by other organisms, obstacles to the continuous preservation of the cultivated algae in a healthy state of growth, efficient harvesting, and the choice of the most suitable algal forms. The last question depends much on what is expected from the algal crop. *Chlamydomonas* and *Tribonema*, used in Germany (Göttingen, Essen), are valuable for fat production. If carbohydrates or proteins are wanted, other algae may be more suitable.

In America the centres of investigation are in Chicago, Stanford (California), and Austin (Texas). Not enough has been published yet to judge the progress. Neither in Britain nor in other countries does any large-scale work seem to have been done. It is much to be regretted that no initiative has been taken in Britain. We cannot afford to wait until others are far advanced.

It is already evident that the nutrient mixtures of inorganic salts habitually employed are not in every case sufficient to support continuous growth, but that certain additional chemicals, in very small concentrations, are also required. It is not easy to supply them in the optimum concentrations, which are affected by mutual precipitation, and by the uptake in algal metabolism and the changes of *p*H connected with it. Furthermore, the maximum rate of multiplication can, in many instances, not be attained at all in inorganic solutions under controlled conditions, owing to the slow synthesis in the algal cell of indispensable organic compounds. The rate of growth is much increased by the addition of such substances, which are called growth factors.

In nature, these growth factors are produced by other organisms; they play an important part in the mutual relationship between the members of an ecological community. The sudden appearance or disappearance of an organism seems often to be caused by an alteration of the equilibrium between the members of the community. It is possible to show experimentally that substances produced by bacteria and fungi favour the growth of certain algae. In other instances the influence is deleterious, either owing to competition for nutritive substances, or to the production of toxic compounds which are called antibiotics. Whether algae themselves produce antibiotics is still controversial. That they may contain toxic substances is known in the case of certain *Myxophyceae* and *Cryptomonadineae*.

A favourable influence on one organism is also often exercised by another one in the production of nutrient substances; an organism may lack the enzyme to split a molecule into compounds which would provide it with food. The breakdown of proteins is, for instance, in nature generally divided into consecutive steps in which several microorganisms may be involved. Algae often benefit from one of the intermediate products, and may multiply suddenly in a surprising way when such substances are supplied. Similarly, polysaccharides are decomposed, especially anaerobically in the bottom deposits of quiet waters, giving rise to substances which favour the development of many algae. On the whole, hexoses do not play so great a role as was attributed to them by earlier workers. Fatty acids, especially acetic acid, are more generally formed and available to algae, and are readily metabolized.

In cultivation, those algae which have been shown to grow better in the presence of organic substances can usually be caused to thrive by the addition of yeast extract and similar mixtures. In the elucidation of vitamin requirements one must depend on chance as long as no strictly synthetic media are available. Such media should contain every ingredient as a known chemical individual, so that the composition of the whole solution can be readily controlled. Still further ahead lies the ideal nutrition experiment, in which the fate of single substances inside and outside the living cell is followed up. For an approach of this kind, ordinary chemical methods will not always be sufficient; to supplement them, physico-chemical tests—for instance, those which use 'tracer' chemical elements (e.g. carbon, phosphorus)—are now available. Pure culture material of algae is indispensable.

Organic compounds are generally utilized only by algal species occurring at places rich in decaying matter, e.g. a great many flagellates and other unicellular algae. The majority of the higher forms have to rely on those organic compounds which are provided by their own photosynthesis. The differences are decisive for the ecological standards of the various algae. It is, however, not safe to reverse the reasoning, and to draw conclusions as to the physiological properties of the species from the state of the place where they are

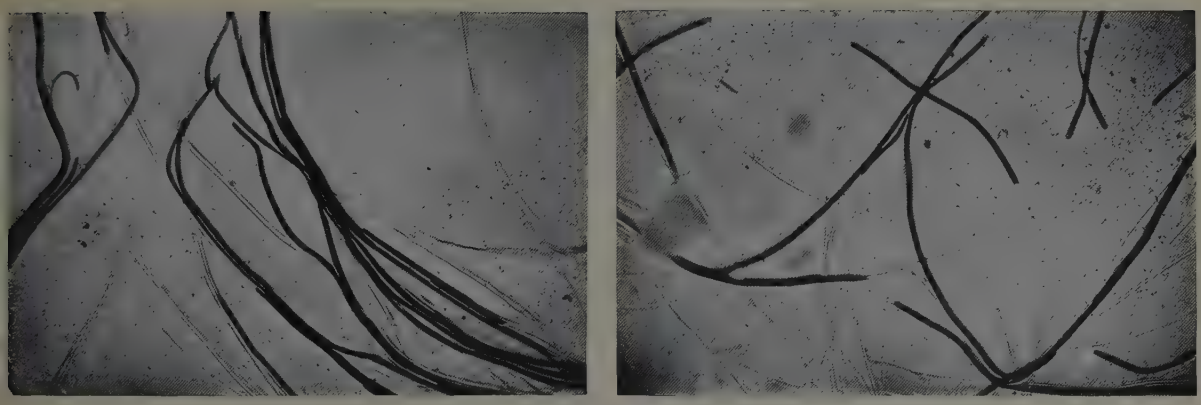


FIGURE 1 – Phormidium *spec.* (*Myxophyceae*) *in pure culture on agar, showing paths of moving trichomes* (× 100).

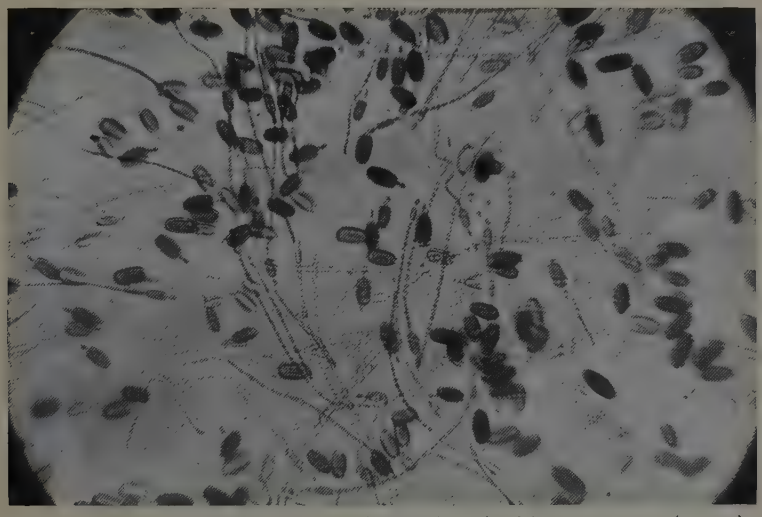


FIGURE 2 – Cylindrospermum *spec.* (*Myxophyceae*) *with spores, on agar* (× 100).

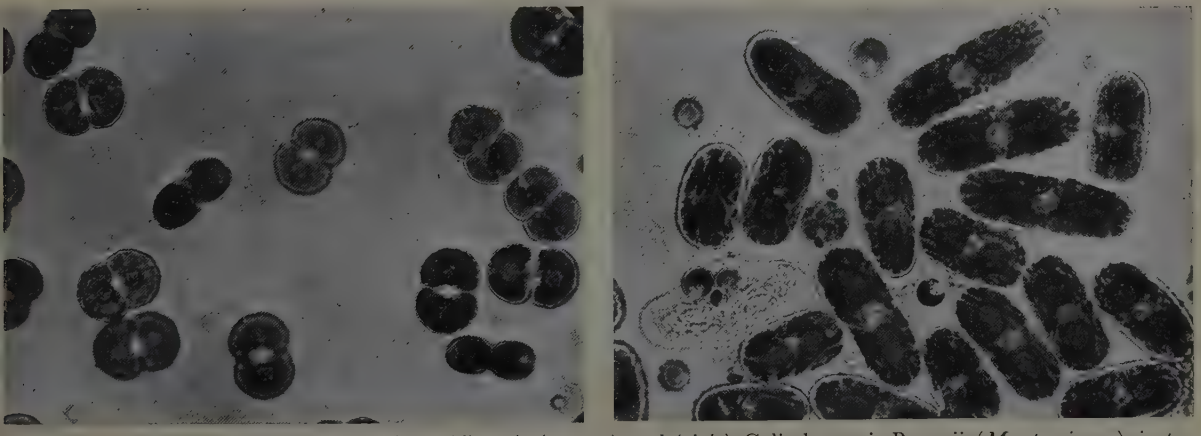
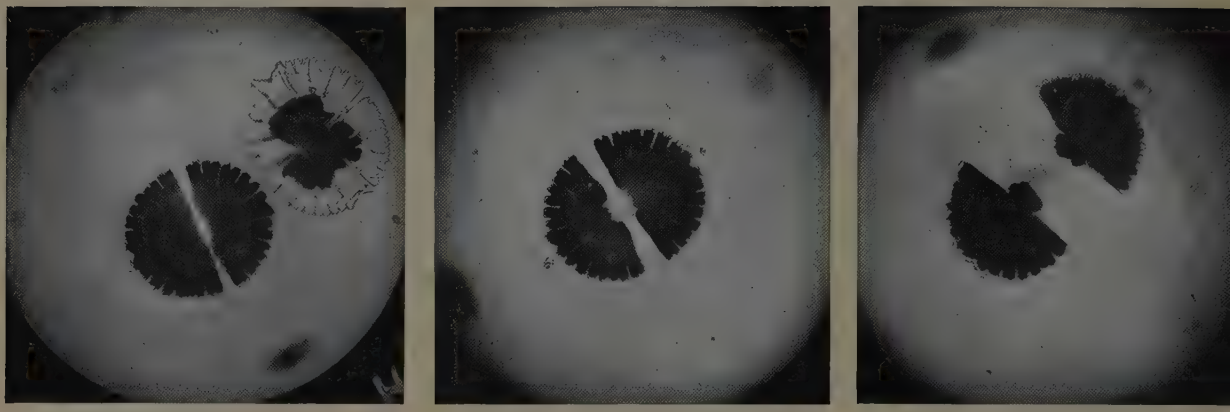
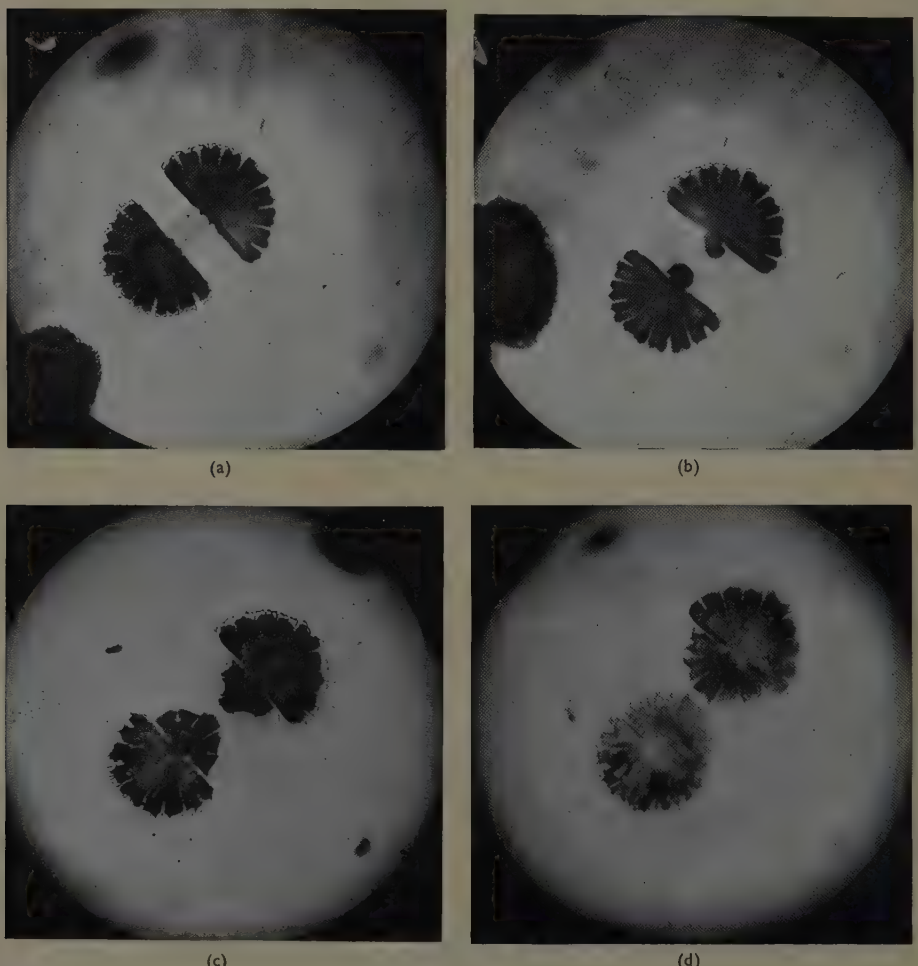


FIGURE 3 – (*Left*) Cosmarium laeve (*Desmidiaceae*) (× 300) *and* (*right*) Cylindrocystis Braunii (*Mesotaeniaceae*) *in pure culture on agar* (× 300).



(a) (b) (c)

FIGURE 4 (a–c) – Micrasterias rotata (*Desmidiaceae*); *three stages of cell division; culture material;* (a) 17·03, (b) 18·11, (c) 20·03 o'clock (× 100).



(a) (b) (c) (d)

FIGURE 5 (a–d) – Micrasterias denticulata (*Desmidiaceae*); *four stages of cell division; culture material;* (a) 10·03, (b) 10·50, (c) 12·12, (d) 14·08 o'clock (× 100).

found. Algae which live in dirty water may still be unable to make use of the organic substances within easy reach. Only cultural experiments can decide the issue. Even when a species is decidedly favoured by certain organic compounds, this need not be caused by their utilization, if other organisms are not excluded. Thus *Polytoma* and *Polytomella* were once believed to be sugar-flagellates, whereas in fact they live on fatty acids.

Algae are often the main food of animals and their larvae. To learn more of their conditions of life, and the way they are taken in and consumed, is a matter of urgency in the efforts to grow more food in rivers, lakes, and even the sea. It is already known, e.g. from experiments in the United States, and in Bohemia and France, that the productivity of fish-ponds can be substantially improved by addition of fertilizers, but that the process has to be watched carefully and adjusted to the kind of fish to be reared. On the other hand, algae may cause serious trouble in waterworks, in small fish-ponds, and even on the soil of commercial gardens and on house walls, so that the need for algicides is obvious.

During the last few decades it has become increasingly obvious that descriptions of many algae were built on a very insecure foundation. This is not so in every group, but there are a number of the simplest as well as of the more complicated families, all commonly occurring, where the degree of variability cannot properly be estimated without culture experiments. Differences in two samples of natural material of the same alga may be due either to hereditary features, or to modification by the conditions of life in the habitat. If the whole population is modified in the same way, it may easily be mistaken for a different taxonomic unit. This has often happened in members of the *Euglenineae*. In many Chlorococcaceae the formation of colonies has been used as a characteristic of genera and even families. It is not possible to do without colony formation as a taxonomic characteristic. Cell-structure and reproduction do not suffice to differentiate the many species of the Chlorococcales. The same species may occur as isolated cells, as colonies of four to sixteen cells, or as compound colonies comprising many such groups in a more or less regular arrangement. Again, only culture experiments can decide which forms belong to one species, and under which conditions the cells remain united after division. It is quite possible, for instance, that certain species of *Ankistrodesmus*, *Quadrigula*, and *Tetradesmus* are all the same, although at present grouped in different families. Among the more highly organized algae, *Cladophora*, with its many species and innumerable varieties and forms, is an example of the inadequacy of merely morphological investigations for settling taxonomic problems. If we cannot recognize species, it is useless to attribute to them definite physiological and ecological properties.

Whereas culture research is in the first instance useful to describe species more thoroughly, and to determine their range of modification, we shall no doubt soon hear more about algal genetics. In spite of interesting beginnings, a well-organized approach has not yet been made. It was not by chance that F. Wettstein decided to use mosses for his masterly genetical studies, and discarded algae. Among the latter are, so far, few in which sexual reproduction can be induced at will, and there remains the great obstacle that sexually-produced resting-stages cannot be made to germinate with certainty. This was the reason why Mainx's promising experiments on species of *Oedogonium* could not be pursued far enough to give the results he hoped to obtain. A better technique will overcome these difficulties.

For most of the above-mentioned investigations, suitably equipped laboratories are required, in which cultures of algae can be regularly maintained. Collections exist at Geneva, Bâle, and Cambridge (England), and on a smaller scale in Paris, Prague, and Uppsala, and at various American laboratories. Most of them are kept by specialists for their own use only. None of them has an assured future, except to some degree that at Cambridge, for which the university took responsibility. Yet it is all-important to preserve the strains used in standard investigations, for further research and comparison.

For these reasons, international co-operation is needed to establish at least one specially built and equipped laboratory of experimental algology as a centre for the various lines of research, and as a source of cultures and advice. It should also be willing to demonstrate methods to inquirers. How necessary such a centre is, the writer knows from his own large correspondence. Its role cannot be played satisfactorily by any of the stations at present devoted to algal research, owing to their narrow restrictions in extent and means, while physiologists, biochemists, and others cannot be expected to acquire the necessary familiarity with the algae and related small organisms without expert assistance. This difficulty will increase in the near future, and the time has come for improvement.

The development of enzymology

P. F. FLEURY and J. E. COURTOIS

Enzymes have been used in fermentation processes for thousands of years. Study of their mode of action has revealed their vital role in intermediary metabolism and an intimate connection exists between them and certain vitamins and chemotherapeutic agents. There is indeed scarcely any constituent of living cells which is not associated in its production and decomposition with some enzyme system. In clinical medicine, determination of enzyme levels in the blood has become of considerable diagnostic value.

Research on enzymatic reactions began in the eighteenth century, when Réaumur, and afterwards Spallanzani, observed that the gastric juices dissolved meat. In 1814, Kirchhoff pointed out that the germinated seeds of barley contained a substance able to convert into sugars not only the starchy matter of the grains themselves, but a certain added quantity as well.

The separation of this substance, amylase—and thus the discovery of the first enzyme—was due to Payen and Persoz. On 17th June, 1833, they presented (through J. B. Dumas as intermediary) a communication to the *Académie Royale des Sciences*. They announced the separation from malt of 'a solid, white amorphous substance, insoluble in alcohol, but soluble in water and dilute alcohol. Heated at 65–70° C with starch granules, it possesses the remarkable power of quickly separating the envelopes from the transformed interior substance, the dextrin. . . . This particular property of separation has decided us to give to the substance that possesses it the name of diastase, to express precisely this fact.'[1]

In a wider sense, the name of diastase was for a long time given to other substances of similar properties, but gradually the term enzyme (Greek 'in yeast') was substituted for it. However, the use of the suffix 'ase' was established in the nomenclature of enzymes (amylase, phosphatase, etc.).

The original paper of Payen and Persoz mentions some properties of diastase that were later found to be fundamental characters of enzymes: (*a*) the thermolability—'If the solution of diastase is heated to boiling, it loses the power of acting on starch and dextrin'; (*b*) the considerable disproportion between the quantity of enzyme introduced and that of the transformed substrate—'When the extraction of this new immediate principle is made carefully, its activity is such that one part by weight is sufficient for rendering soluble in warm water the contents of 2000 parts of dry starch granules, and transforming the dextrin into sugar'; (*c*) the possibility of purifying the diastase by precipitation with alcohol from its aqueous solution. Incidentally, to the end of the last century this precipitation remained the principal method of purifying enzymes.

[1] From the Greek word *diastasis*, which means 'separation.'

Between the discovery made by Payen and Persoz and the present time, three chief periods can be distinguished in the development of our knowledge of enzymes: the stage in which the notion of an enzyme was formed and defined, the stage of generalization, and the stage of the considerable expansion marking the last twenty years or so.

CONCEPTION OF THE IDEA OF AN ENZYME (1833–94)

From 1835 onwards, various workers noted other products possessing the characteristics of diastase, but acting upon different substances; thus pepsin, emulsin, myrosin, trypsin, lipase, sucrase, and urease were successively discovered. In 1877, Duclaux, one of the ablest followers of Pasteur, published an article entitled *Action des diastases ou ferments solubles*. In a dozen pages Duclaux coordinated contemporary knowledge on the subject, and his article may be considered as the basis of the science of enzymology.

GENERALIZATION OF THE IDEA OF ENZYMES (1894–1926)

All the enzymes discovered up to this time were hydrolases, i.e. enzymes decomposing the substrate by hydrolysis, the H and OH groups of the water attaching themselves to the ends of a broken valency bond. It was thus an important advance when, in 1894, E. Bourquelot and G. Bertrand discovered a new class of enzymes, viz. the oxidases, able to add not water but oxygen to the substrate.

The study of oxidases led G. Bertrand to suggest the first conception of the constitution of enzymes, a conception which, slightly modified, is now universally accepted. It is as follows. The entire enzyme or holoenzyme is built up of at least two fractions:

(*a*) The apoenzyme, which is always a protein; it is colloidal and thermolabile.

(*b*) The co-enzyme, of variable chemical constitution, frequently a phosphoric ester and sometimes a metallic derivative; very often the co-enzyme, which is non-colloidal, is fairly thermostable.

The discovery of a non-hydrolysing enzyme was quickly followed by that of other enzymes distinct from hydrolases. By compressing yeast Buchner, in 1897, obtained a liquid which converted glucose into carbon dioxide and ethyl alcohol; this preparation, zymase, had the character of an enzyme but catalysed a reaction that had never before been effected except by living yeast cells. This discovery went far to fill the gap that was supposed to exist between 'organized ferments' and enzymes.

In 1902, Schärdinger described the first dehydrogenase. This enzyme, present in milk, removes hydrogen from water, and the hydrogen can be taken up by methylene blue, which is thereby reduced to the colourless leuco-base. About the same time, Neuberg discovered carboxylase, which converts pyruvic acid into acetaldehyde and carbon dioxide. All the enzymes so far isolated catalysed only degradation reactions, but, between 1900 and 1912, it proved possible after many attempts to catalyse various condensation reactions enzymatically. The researches were principally directed to the biosynthesis of holosides and heterosides, and were carried out by Croft-Hill, Bayliss and Armstrong, Bourquelot, Hérissey and Bridel, and others. Finally, in 1906, a fundamental discovery was made by Harden and Young, who observed that, in alcoholic fermentation, sugar is first transformed into a diphosphoric ester of fructose. The isolation of intermediate compounds of glycolysis, and the researches made at the same time by Hopkins on lactic acid in muscular contraction, constitute the beginning of those studies on intermediary metabolism that were to develop so fruitfully in Britain.

DEVELOPMENT OF ENZYME CHEMISTRY (1926–50)

At the end of the second period, enzymes were viewed as specific thermolabile catalysts, but none of the basic problems they set—isolation in the pure state, constitution, specificity, mode of action—had been resolved. The period from 1926 to the present day has been marked by great advances in these different domains.

It was inaugurated in a spectacular way by the work of the American school. In 1926, James Sumner described the separation of urease in the crystalline state. Jack-bean flour is extracted with water, and the solution is treated with acetone; on cooling, crystals are deposited, the ureasic activity of which is not sensibly modified by further crystallizations. These crystals of urease resemble the globulins in composition and general properties.

This important discovery was the starting-point of a long series of researches that yielded important data on the chemical structure of numerous enzymes.

PURIFICATION OF ENZYMES

Holoenzymes have the character of proteins, so that enzymology has gained much by advances realized in the purification of proteins. The principal current methods of purification are fractional precipitation by salts (e.g. ammonium, sodium, and magnesium sulphates, alkaline phosphates); precipitation by organic solvents miscible with water (methyl alcohol, acetone, dioxan); and adsorption (e.g. with alumina) and elution. To these chemical methods, physical methods may be added, e.g. dialysis under different conditions, particularly electro-dialysis; ultrafiltration; and differential electrophoresis. It should be noted that these methods yield very active preparations but not necessarily pure holoenzymes in the chemical sense. The most active preparations obtained, even when crystalline, almost always contain an associated fraction devoid of enzymatic activity.

The separation of enzymes of very distinct specificities is relatively easy—a classic example is that of the enzymes in the pancreatic juice: proteases, amylase, and lipase. On the contrary, it is very difficult and sometimes almost impossible to separate enzymes of very near specificities, e.g. the glucidases of almonds or phosphatases of seeds (J. Courtois). Indeed, enzymes transforming substrates of similar chemical constitution have in common numerous physico-chemical characters that make their separation very difficult without denaturation of the protein apoenzyme. An important outcome of the availability of enzymes in an advanced degree of purity has been the

elucidation of the chemical structure of different co-enzymes.

CHEMICAL CONSTITUTION OF CO-ENZYMES

It is possible by dialysis to separate from Buchner's zymase a thermostable substance, co-zymase, which is the co-enzyme of numerous dehydrogenases. From 1920 on, von Euler and Myrbäck endeavoured to purify this co-enzyme, and, about 1930, they showed that it is a nucleotide containing adenine. In 1934, von Euler on the one hand, and Warburg and Christian on the other, isolated nicotinamide from the co-enzymes of dehydrogenases, and shortly afterwards biochemists identified this substance with vitamin PP (pellagra-preventing).

In the same year, Theorell proved that the "yellow enzyme" hydrogen carrier from yeast can be separated by dialysis into its apoenzyme and co-enzyme. The yellow enzyme is reconstituted by reunion of these two fractions, but—a new fact of essential importance—the co-enzyme was identified with a phosphoric ester of riboflavin, the vitamin B_2. For the first time, a connection was established between enzymes and vitamins.

In 1935, Lohmann and Schuster showed that co-carboxylase is a phosphoric ester of vitamin B_1: this fact confirmed the work of Peters and his co-workers at Oxford, who had already shown that vitamin B_1 intervened in the metabolism of pyruvic acid. In the table (p. 147) is given a list of vitamins forming part of certain enzymes; it will be noted that in some cases holoenzymes of distinct specificities have the same co-enzyme. Co-dehydrogenase I (co-zymase) is the co-enzyme of a number of distinct dehydrogenases acting respectively on diphosphoglyceric aldehyde, lactic, malic, α-glycerophosphoric, β-hydroxybutyric, and formic acids, glucose, some acyclic alcohols, etc. Other similar facts tend to show that in diastatic reaction the apoenzyme plays an essential part, since it seems to guide the specificity of the co-enzyme.

It is rather remarkable that in almost all co-enzymes, the vitamin, an essential metabolite, is joined more or less directly to phosphoric acid. Courtois and Barré supposed that this esterification of a hydroxyl radical by phosphoric acid tends to favour the union of the metabolite with the corresponding apoenzyme, this union being effected with the other acid groups of the phosphoric acid. Courtois and Barré observed that a vegetable protein, conamandine, could form insoluble compounds, at about *p*H 3·0–4·0, with numerous phosphoric esters, and pyrophosphoric and orthophosphoric acids. Esters of cyclic hydroxy-compounds give the most stable combinations.

A very important development in enzymology is the notion of antimetabolite. In 1940, Woods found that *p*-aminophenyl sulphonamide,

$$NH_2\text{-}C_6H_4\text{-}SO_2NH_2$$

has an opposing action to that of *p*-aminobenzoic acid, $NH_2\text{-}C_6H_4\text{-}CO_2H$. This *p*-aminobenzoic acid is an essential metabolite, necessary to the development of numerous micro-organisms; it seems to be combined in the form of still imperfectly known enzymes.

The sulphonamide having a chemical structure similar to that of this metabolite can displace it from its combination with the apoenzyme, and substitute itself to form a new compound without enzymatic action. Equilibrium between metabolite and antimetabolite sulphonamide is governed by the law of mass action; it depends on the respective concentrations of the two substances and on the stabilities of their combinations with the common apoenzyme.

This discovery represented the first contact between chemotherapy and enzymology. It explained the bacteriostatic action of sulphonamides, by assuming the formation of inactive combinations which substitute themselves for enzymes indispensable to bacterial metabolism. During recent years, other metabolites having a chemical relationship with vitamins acting as enzymes (sulphopantothenic acid, pyrithiamine, etc.) have been prepared. It is likely that some of them may be used in therapeutics, and chemotherapy may thus receive a new orientation.

The list of enzymes of accurately known constitution is not limited to those of which the co-enzymes contain vitamins and which have a certain similarity to nucleoproteids. Some enzymes show clear analogies to respiratory pigments; catalase and peroxydase are iron proteins rather similar to haemoglobin. In them, iron is joined to a tetrapyrrolic ring connected to a holoproteid fraction. The Cambridge biochemists Keilin, Mann, and Tissières, have shown that some oxidases are copper proteins somewhat similar to the haemocyanins, the respiratory pigments of molluscs and crustaceans.

Finally, various metallic ions can activate certain enzymes, and the activation becomes greater with greater purity of the enzyme. Such enzymes are said to possess a dissociable metallic constituent (J. Roche). It seems doubtful whether the

VITAMIN CONSTITUENTS OF CERTAIN ENZYMES

Vitamin revealed in holoenzyme	*Chemical structure of co-enzyme*	*Corresponding holoenzyme*
B_1 (thiamine)	Pyrophosphoric ester of thiamine	Carboxylase of α-ketonic acids
B_2 (lactoflavin)	Orthophosphoric ester	Yellow enzyme of Warburg
	Orthophosphoric ester bound to adenylic acid in the shape of dinucleotide	Second yellow enzyme *d*-aminoacid oxidase xanthine oxidase fumarate hydrase diaphorase aldehydedehydrases
B_6 (pyridoxine)	Phosphorylated pyridoxal	Decarboxylases of different L-amino acids transaminases
	Pyridoxamine phosphate	Glutamic and aspartic transaminases
PP (nicotinic acid amide)	Dinucleotide with nicotinic acid amide-ribose-$(PO_3)^n$-ribose-adenine n = 2-codehydrase I n = 3-codehydrase II	Varied dehydrogenases of different specificities
Pantothenic acid	Co-enzyme A (phosphoric ester?)	Enzymes of acetylation and conjugation
Inositol	?	Certain amylases (Williams) absent in other purified amylases (Fisher and Bernfeld)
F (pteroylglutamic or folic acid) ..	?	Enzymes oxidizing tyrosine in liver
H′ (*p*-aminobenzoic acid)	Peptide?	Imperfectly defined enzymes taking part in bacterial intermediary metabolism

metallic ion is the co-enzyme. It may serve either to promote the union of enzyme and substrate, or to stabilize the union of apoenzyme and co-enzyme. Thus manganese activates arginase, magnesium enolase, and magnesium (and, to a smaller degree, zinc and cobalt) alkaline phosphatases. This participation of metals in enzymatic reactions provides an explanation of the biochemical role of trace elements, i.e. elements normally present in tissues in very small quantities (G. Bertrand).

Knowledge gained in the last two decades must not make us forget that the constitution of several hundred enzymes is as yet quite undetermined.

ROLE OF ENZYMES IN INTERMEDIARY METABOLISM

For about a century, enzymes were thought to operate independently of one another, but a thorough study of intermediary metabolism has shown that the reactions occur in a series of stages, and that in each stage a new enzyme plays its part. Every enzyme transforms a metabolite which has arisen in the preceding stage from another enzymatic action. At present, the best-known intermediary metabolism is that of glucose (alcoholic fermentation and muscular glycolysis). During these processes, energy contained in the molecule of glucose is degraded progressively by a chain of reactions successively catalysed by phosphorylase, phosphoglucomutase, hexokinase, phosphopherase, zymohexase, triosephosphate isomerase, a first dehydrogenase, phosphoglyceric acid isomerase, enolase, another phosphopherase, a second dehydrogenase, and so on.

Energy produced in certain reactions catalysed by enzymes can be accumulated for a time in certain intermediary substances such as Lipmann's strongly bonded phosphate compounds.

These complex reactions (scission, isomerization, transfer) are sometimes accompanied by a process of re-synthesis. One of the best-known enzymes of those endowed with the power of synthesis is the phosphorylase of the Coris. It catalyses the reversible reaction: *n*-glucose-1-phosphate $\rightleftarrows$ polyholoside with *n* glucose + *n* orthophosphate. With the phosphorylases of animal origin the polyholoside synthesized resembles glycogen; with vegetable phosphorylases, located more specially in amyloplasts (Yin and Sun), a starch-like substance is obtained. By use of enzymes of the same type, sugars such as sucrose have been obtained by biosynthesis.

We shall next point out the importance of pherases. These enzymes catalyse the transference of a radical or grouping from one compound to another; they are essential in intermediary metabolism. Ten years ago, Braunstein described the aminopherase or transaminase that carried, reversibly, the amino group from an α-aminoacid to an α-ketonic acid, as, for example, in the reaction: L-glutamic acid + pyruvic acid $\rightleftarrows$ α-ketoglutaric acid + L-alanine. The Krebs tricarboxylic acid cycle is another example of these chain transformations. Up to the present, however, we are familiar only with fractions of different chains.

These researches accentuate the narrow specificity of action of enzymes. Solution of this still unsolved problem may probably be achieved by the same methods as that of the parallel problem of the specificity of antigens and antibodies.

PATHOLOGICAL VARIATIONS OF ENZYME ACTIVITY

For some ten years, determination of the activity of certain enzymes has been a routine practice in clinical biology. The pathological changes observed facilitate diagnosis, and a progressive return to a normal value is a sure indication of the efficacy of a therapeutic treatment.

We shall give some of the most characteristic examples. H. D. Kay of Reading showed that the activity of serum phosphatase in an alkaline medium is related to the functioning of the skeleton; the normal values are higher in young individuals, with the skeleton still developing, than in adults. The activity of serum phosphatase increases notably in various bone diseases, e.g. osteitis, rickets, osteomalacy, osteosarcoma; its return to a normal value is a reliable test of recovery. Serum also contains, in smaller proportions, a phosphatase reacting in a slightly acid medium, and the activity of this phosphatase considerably increases in cancer of the prostate with metastases. Recovery, full or partial, of the patient is accompanied by a progressive fall in activity.

The activity of different esterases of serum (tributyrinase, cholinesterase, procainesterase) is related to the state of the liver; determinations of it furnish a very useful factor in the diagnosis of hepatic affections. During acute pancreatitis a large overflow of amylase into the serum is observed; the excess of enzyme diffuses into the urine, where it can be detected. The activity of hyaluronidase is related to fertilization, and to certain diffusion phenomena in mucous membranes.

CONCLUSIONS

For more than a century, advances in enzymology have equalled those made in other, perhaps more spectacular, branches of biochemistry and biophysics. Enzymology represents, in some ways, a cement that unites these branches, which the progress of science and the resulting specialization tend to separate. It is, however, evident that, more than a century after the discovery of Payen and Persoz, the study of enzymes has not yet brought a satisfying solution to all the problems raised. Moreover, many new problems, of the most varied types, continue to arise—but is not that the symptom of full vigour in a science?

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Cavitation in liquids

E. G. RICHARDSON

Research on the impact of solid bodies on liquids, and on the cavitation resulting from the movement of such bodies through liquids, begun half a century ago as an academic study, has assumed great practical importance. It plays a part, for example, in the design of ships' propellers, in the study of certain types of metallic corrosion, and in the application of some ultrasonic techniques. Dr Richardson here summarizes our knowledge of the subject.

In 1897 Worthington published a paper on the splashes produced by steel spheres, or by water drops, falling on to a plane water surface. Subsequently he published a number of photographs, taken by the then novel flashlight method, in a book called 'A Study of Splashes' One of these is reproduced here (figure 1) to show a feature of the low-speed entry of a solid sphere into a mass of liquid, i.e. the rise of liquid in the shape of a jet to form the splash behind the entering sphere. It illustrates the cavity, visible as a black tapering 'sock,' which has been formed by the entry of a 5 cm diameter ball dropped from a height of 9 ft. At this instant the ball itself has passed outside the picture below the field of view, which is limited by the white circle thrown on the plate by a light and lens behind the tank. The solid imparts a centrifugal impulse to the liquid, to leave a cavity into which the air rushes. Such cavities are also formed when a drop of liquid falls at sufficient speed into a mass of the same liquid, whether the latter is stationary or moving. Thus the scientific origin of the 'purling of the brook' of which the poet speaks is to be sought in the action of drops of liquid falling into the main stream, in so doing forming cavities which emit sounds of a frequency roughly in inverse proportion to their volume as the air is sucked in, and expelled again when the hole collapses.

This, the formation of hollow spaces behind a solid body entering a liquid, is one of the two aspects of cavitation which it is the purpose of this article to discuss. With the advent of the aeroplane, study of the impact of a solid body on a liquid became an urgent matter. The force on the body entering the liquid is due partly to the skin friction of the liquid moving over its surface up to the point when the liquid leaves it to form the cavity, and partly to the work done in imparting momentum to the liquid as the entering body clears a way for itself. If there is a pronounced splash, work is of course also done in imparting vertical momentum to the surface. In fact, however, most of the momentum has a horizontal or nearly horizontal direction. This can be seen if a number of tiny air bubbles are dispersed in the liquid just before the sphere enters, so that a rapid series of superposed photographs can show, by the tracks of the air bubbles carried with the liquid, the motion imparted locally to it. This is the technique developed by Schlichter; it is illustrated by figure 2, which shows a series of superposed photographs (taken by the Egerton stroboscopic camera) of the entry of a sphere into water, in which successive positions of individual air bubbles show the tracks of the local impulse given to the water.

The practical importance of such impact forces was realized when heavy seaplanes touched down on to the sea. Although such a 'landing' is oblique, and the craft does not penetrate the water far, yet a considerable cavity can be formed under these conditions, the creation of which may give rise to dangerous pressures on the float or hull structures. The magnitude of these forces was first investigated, both with small models and at full scale, at the Marine Aircraft Experimental Station of the Royal Air Force.

The other reason for studying the entry of bodies at high speed into water, and the shapes of the cavities they produce, is associated with belligerent attack on ships below the water-line.

Whether for peaceful or warlike objects, such water-impact studies are much too costly in time and material to be carried out at full scale except as a check on research with models, so that it becomes very important to know by what criterion the results obtained on a small scale are to be converted to full scale. The criterion by which most aerodynamic research is scaled is the well-known parameter of Osborne Reynolds, but when a liquid-gas surface is involved, as it is in this instance and in the motion of all surface craft, the

viscosity which enters into the Reynolds number becomes unimportant, and the Froude number (involving the quotient of the square of the velocity by the linear dimension) becomes more significant.[1]

The writer has been able to show that all initial cavity-shapes formed by spheres entering liquids may be scaled on such a basis, and that the viscosity of the liquid plays little part. Thus, the sizes of the cavities formed by a sphere shot at equal speeds into water or into glycerol are the same. The only effect of viscosity in the latter is to delay the breakaway, and subsequent rise to the surface, of the entrained air. It can be shown that the relative density of the liquid to that of the atmosphere should, for correct scaling, be changed in proportion to the depth at which the cavity is observed, in order to conserve hydrostatic pressure. As such cavities do not extend to great depths, this correction is a minor refinement. Model dropping tanks have nevertheless been built in enclosed chambers in which the effect of reduced air pressure on the cavity may be investigated. Though there is no observable change in the initial shape of the cavity, it is noted that, by the return of the liquid, it seals up more often first at the surface when normal atmospheric pressure rules; if the atmospheric pressure is reduced to about one-fifth of normal there is a pronounced splash, the cavity remains open in bell shape at the surface, and the liquid seals first lower down in the cavity. Figures 3 and 4 show this difference: figure 3 is of an entry under atmospheric pressure after the cavity has sealed at the surface, and figure 4 shows two stages of a similar entry under reduced pressure, with the cavity flaring out at the surface and sealing midway. Surface tension has little effect at the entry speeds here considered, because the impact forces are large.

In aerodynamics we often hear nowadays of another parameter, i.e. the Mach number, when the speed of motion is comparable with that of sound in the medium. It is now readily possible to fire spheres into water at speeds approaching that of sound in water (1435 m/sec), and shock waves are then set up in the water, but the cavity produced conforms with those at a lower speed of entry (on a Froude number basis). Thus—fortunately—we do not need to trouble ourselves with Mach numbers in this branch of fluid dynamics.

Another type of cavitation is that which may be formed when a body completely submerged travels at such a high speed that a vacuous cavity is set up, or at least a region in which the pressure is reduced to the saturation pressure of the vapour of the liquid concerned. The term 'cavitation' for this phenomenon was due to Froude.

Cavitation is conditioned by the maximum tension, or negative pressure, which a liquid can tolerate before breaking up into 'lumps,' like a plastic solid pulled opposite ways. There has been much argument, based on both theory and practice, as to what this critical tension is. Berthelot, who first considered it, sealed up a nearly boiling liquid in a strong glass vessel and waited for breaks to occur in the continuity of the liquid as it cooled. From his experiments he estimated that water could stand 200 atmospheres before breaking up and leaving vacua in the tube. However, those who have repeated these and analogous experiments, with direct measurement of the critical tension, report much lower values, and Temperley thinks that a liquid can withstand only about ten atmospheres negative pressure.

Because the tips of ships' propellers move faster than other known submerged bodies, it was in this case that cavitation due to high-speed underwater motion was first noticed. The first water channel in which cavitation on propellers, driven by motors from outside the tunnel, could be studied was built by Sir Charles Parsons in 1910. His earliest experiments with cavitating model propellers in a tank of water were made at the beginning of this century. Out of them developed the tunnel, with the propeller submerged in a fast-flowing stream of water.

This kind of cavitation is closely related to that which we have already discussed. In both cases the liquid secedes from the body where the hydrostatic pressure on it falls practically to nil, so that there is no force to make the boundary layer of liquid adhere to the surface. Those shapes of bodies causing the largest acceleration of the fluid at sharp corners will cavitate at the lowest mean speeds of propulsion. Thus a disk with its axis in the direction of flow of the liquid will readily form a large cavity in the water behind it, similar to that on entry, if the special features of a free surface be excluded (figure 5). It must be remembered that the entry cavity can be formed at a much lower speed and is not a near vacuum, for, as we have remarked, it rapidly fills with air from the atmosphere above. Relative speeds of the order of 6 m/sec are required to produce the cavities behind a submerged object.

[1] R. E. Froude was a pioneer British engineer, the first to make measurements of the resistance of model ships towed in a canal, and to correlate such measurements with full scale.

FIGURE 1 – *Entry of sphere 5 cm in diameter into water at a speed of 2 m/sec. (Worthington) (approx. full size)*

FIGURE 2 – *Streamlines of water disturbed by entry of sphere, the motion being shown by the traces of the air bubbles in the superposed photographs. (U.S. Navy)* (× 0.25)

FIGURE 3 – *Entry of sphere 2·5 cm in diameter at 9 m/sec, showing 'surface seal' of cavity. (Reduced)*

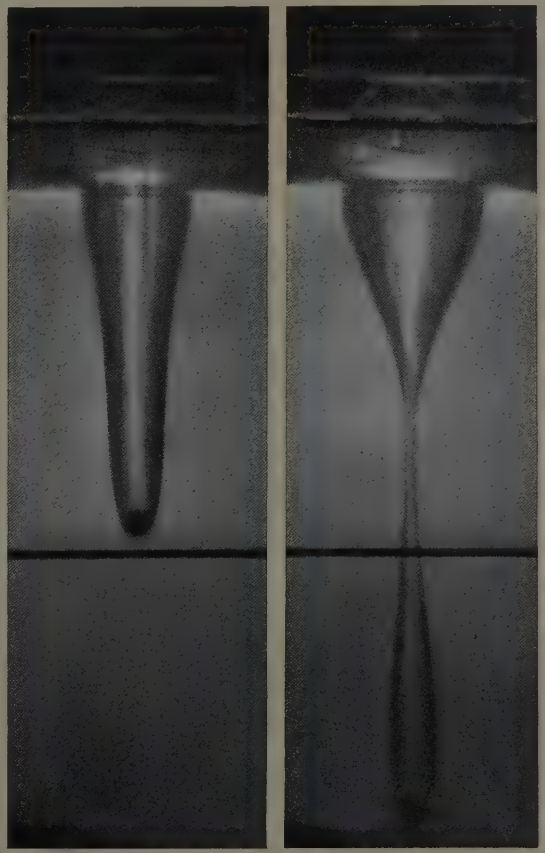

FIGURE 4 – *Entry of similar sphere, showing 'deep seal' of cavity. (Reduced)*

FIGURE 5 – *Disk of* 10 *cm diameter in cavitation tunnel with water flowing at* 6 *m/sec.* (× 0·5)

FIGURE 6 – *Propeller in cavitation tunnel.* (*Gawn*) (× 0·25)

On a less sharply curved body—say in the shape of a fish—when the speed is raised at the 'shoulders,' or places of greatest curvature, cavitation first appears as a chain of little vaporous cavities which tend to collapse, giving an appearance of soapsuds. If vortex formation is going on at any point on the body before cavitation, the cores of vortices seem to act as nuclei for the vapour. As the speed increases, so do the rate of vapour formation and the size of the bubbles, until the bubbles combine, forming a sock which envelops the tips of moving propellers or the whole rear portion of the stationary obstacle.

Figure 6 is a photograph of a propeller in a cavitation tunnel in which, owing to the rotation of the blades, the cavities are left behind in the form of helices. The pressure of the atmosphere over the water affects the nature of these cavities, just as it affects those formed on impact. Naturally, the presence of dissolved air in the water will encourage cavities by forming nuclei, so that, for standardization, all propeller tunnels have the air removed by continual pumping. For the same reason, leakages of air into the water through the joints of the tunnel must be sedulously avoided.

Why, then, is this type of cavitation so closely studied by applied scientists today? Firstly, as Parsons showed, erosion of the metal of the body, especially of the tips of propellers, rapidly spoils the surface and eventually tears it into holes. The surface of the solid becomes pitted by the impact of the water as the cavities collapse. The rate of collapse is such that, as Rayleigh showed, pressures of several thousand atmospheres may be set up inside the bubbles. The erosion is due to a rapid series of hammer-blows and may, in fact, be imitated by playing a high-speed jet of water on the spokes of a rapidly revolving wheel. Secondly, even if this erosion should be minimized as the result of the metallurgical studies of propeller materials now going on, the hydrodynamic resistance of a body having an attached cavity is much reduced. Thus the sphere of figure 3 has a resistance coefficient, at a speed of entry of 9 m/sec, of 0·28 as against 0·40 for a fully submerged sphere. This might be thought an advantage until one reflects that the designer relies on this resistance to give the propeller-thrust which drives the ship. In fact, the cavitating tips lose their bite on the fluid, just as do the tips of an aircraft propeller in the rarefied air of the stratosphere. Thirdly, the collapse of the cavities is a noisy process (the 'singing propeller').

Faced with these undesirable concomitants of high speed, scientists are trying by experiments in cavitation tunnels to find the conditions under which the onset of this phenomenon may be deferred to as high a speed as possible. This is sometimes done on the actual propeller; photographs such as that of figure 6 are taken, and the torque and thrust on the propeller are measured at the same time. The writer, however, feels that more can be learnt by observing stationary bodies of different shape in the tunnel, although this means that the running speed of the tunnel must be higher to induce the effect than if a rapidly rotating propeller is being studied.

Meanwhile, one remedy is obvious, viz. to round off the edges of the propeller blades, but this the designer is loath to accept, for it reduces the efficiency of the propeller. Some such compromise may have, however, to be adopted.

There is a third way in which cavities may be set up. We have referred above to cavitation as induced by excessive accelerations in the fluid. These can occur not only in straightforward flow but in the high peak accelerations of the alternating flow in the neighbourhood of submerged ultrasonic generators. There is nothing here specific to the high frequency, but since the acceleration in S.H.M. is proportional to the square of the frequency, the requisite peak acceleration is the more readily reached if the frequency is high. Many of the reported effects of ultrasonic agitation in liquids, such as degassing, the killing of bacterial cultures, and the breaking down of high-polymer molecules, are ascribed to the forces set up therein when the cavities are formed and subsequently collapse on to the surface of the ultrasonic source.

Owing to the difference in acoustic impedance between air (or a vacuum) and water or solid materials, this onset of cavitation limits the efficiency of a high-power ultrasonic signal generator. In this sphere, too, research is being carried out to extend the limit to higher outputs.

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Molecular compounds

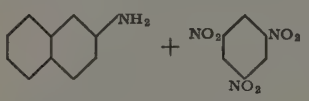
H. M. POWELL

It is not uncommon in chemistry to find that new methods of investigation lead to the discovery of quite unexpected properties in substances so well known that it would seem that there was little further to be discovered about them. Thus, recent research has shown that some familiar compounds can form molecular compounds in which two substances are firmly bound together because, in the crystalline structure, one substance encloses a system of spaces into which the other can fit but from which it cannot escape again.

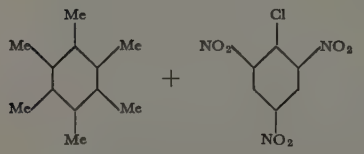
In suitable conditions, such as presence in the same cooling solution, two—or sometimes more—chemical compounds, each capable of a separate existence and having no obvious means of chemical union, may together form a new crystalline substance described as a crystalline molecular compound. Examples in the table (p. 157) illustrate how the ratio of the component molecules may be constant or variable, simple or complex.

The table gives a few examples only, and the arrangement into three groups is merely a convenience for illustrating the manner in which, for the selected examples, the molecular form and ratio of the components may vary.

In type I, considerable variations of both components may be made without affecting the possibility of compound formation or the general formula. Thus the molecular pairs:



and



combine in this way. In these, the molecular ratio 1 : 1 does not require an ordinary chemical linkage between the pairs of molecules, since it may arise from regularity of packing; according to crystal-structure analysis of one such compound no pair comprised of an atom from A and one from B has the short interatomic distance required for a covalent bond. It is reasonable in this group to attribute the compound formation to some pronounced form of residual attraction, possibly involving particular parts of the molecules. This attraction will be present provided certain features of the molecules are preserved—here the three nitro groups or their analogues in one, and the aromatic ring system of the other.

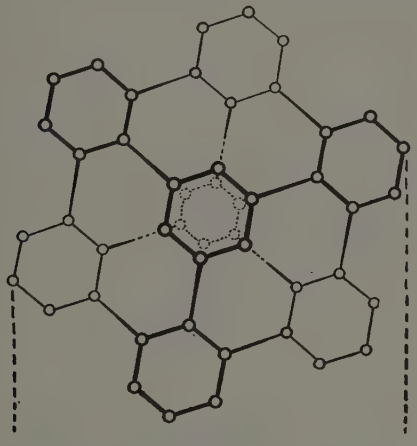
In type II, one component remains constant and the molecules of the second bear some structural resemblance to each other. Although they may differ also in other ways, the chief difference is often one of molecular length, the various molecules being related to each other in the same way as members of a homologous series. In these crystals, a framework of one component leaves a set of parallel, roughly cylindrical, channels in which rod-like molecules of the second component are arranged lengthwise.

Three factors are of importance in relation to this arrangement: (1) As a rule the framework structure is not that adopted by the framework-forming component when it crystallizes alone, so that examination of the structures of the pure components does not provide in any direct manner an indication of substances which are likely to form such compounds. (2) The framework and dimensions of the channels, being subject only to minor variations, restrict the second component to those substances which have molecules of a size and shape which will fit into the available space. Thus the molecules of the normal paraffins fit into channels formed by urea molecules, but the entry into similar combination of the branched isomers is prevented by their excrescences, which cannot be accommodated in the channels. (3) The composition of the compound formed depends on the length of the rod-like molecule which has to be fitted into the cylindrical space. In general, the number of molecules in the channels will be inversely proportional to their lengths, as is found in the dinitrodiphenyl compounds, and it is not necessary that there should be a simple ratio between the number of molecules in the channels and the number of the molecules required to form the framework. This is illustrated by the urea-hydrocarbon series.

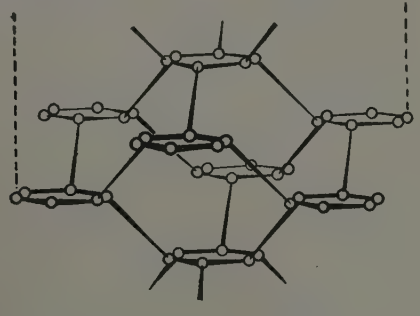
In compounds of type III, one component

remains constant and the possible variations of the second component depend not on chemical similarities but on molecular size. Members of homologous series do not replace each other, but similarly sized molecules may do so. Thus, the series of quinol compounds given in the table has for the second component such chemically different substances as hydrogen sulphide, sulphur dioxide, methanol, acetylene, carbon dioxide, formic acid, and argon. However, similar compounds are not formed by resorcinol, an isomer of quinol, and hydrogen sulphide cannot be replaced by water, methanol by ethanol, or argon by helium.

FIGURE 1 – *Manner of hydrogen bonding of quinol molecules.*



(a) *In plan. Each regular hexagon denotes six hydrogen bonds between oxygen atoms. Hexagons at different levels are represented by different line thickness. The tapered lines, representing the O—O axis of a quinol molecule, show the method of linking to form an infinite three-dimensional cagework. Each taper points downward from the observer.*



(b) *Perspective drawing corresponding to the above. The hexagons denote the hydrogen bonds; the longer lines connecting different hexagons denote the O—O axis of the quinol molecule. The complete structure as found in the molecular compounds consists of the cagework shown, together with a second identical interpenetrating cagework, which is displaced vertically half-way between the top and bottom hexagons.*

Structural investigations show that in these compounds quinol forms a structure which encloses molecules of the second component in cavities of limited size. In such compounds, which have been called clathrate compounds, each molecule of the second component is enclosed in a separate molecular cage from which it cannot escape. The manner of enclosure is illustrated in figures 2 and 3.

The following points of behaviour in the series emerge from a study of the structure:

(1) The tenacity with which the normally volatile constituent is held in molecular association with quinol is not explained by the mutual attraction of the components. This may be illustrated by the argon compound. The van der Waals interaction of argon with resorcinol does not cause molecular compound formation, and no very different interaction is to be expected when the isomeric quinol replaces resorcinol. Yet the crystalline argon compound shows a negligible pressure of argon and may be preserved unchanged for prolonged periods. This is attributed to the imprisoning action of the molecular cages in which the argon atoms are enclosed. As may be seen in figure 3, each atom is closely shut in between the surrounding quinol molecules, which are themselves held together by comparatively strong hydrogen bonds. To escape from its enclosure, the atom must pass through an escape

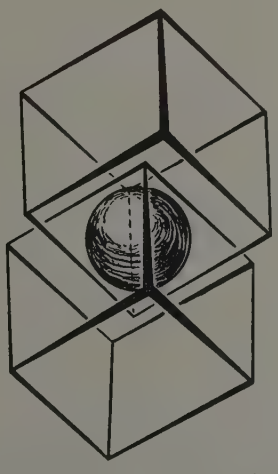
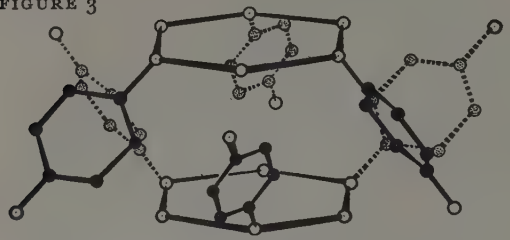
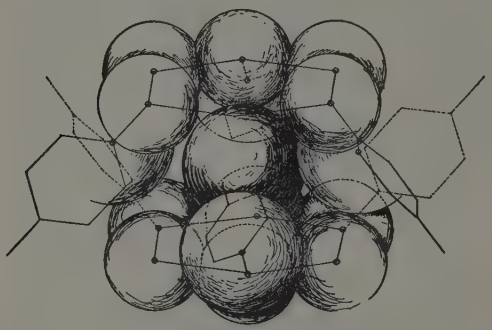


FIGURE 2 – *Schematic representation of enclosure. The enclosed molecule is represented by a sphere imprisoned by two interpenetrating cage structures. Each edge of the cage may be looked upon as containing one quinol molecule, and the real structure consists not of the limited cagework shown, but of the indefinitely extended pattern obtained by the prolongation of the edges to form an array of similar cages.*

FIGURE 3



(a) *The positions of the six quinol molecules that form the immediate surroundings of an argon atom are shown in a perspective drawing. This is deceptive because the centres of the atoms are shown, and the space occupied by the atoms cannot be shown at the same time.*



(b) *The spaces occupied by the atoms are indicated in a drawing on the same scale as that above. A few only of the atoms surrounding the central argon atom are shown. They are distinguished from those which have been omitted by small circles drawn around their centres. Broken lines are used to indicate that a part of the structure so represented lies behind some portion drawn with full lines.*

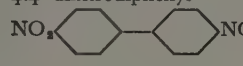
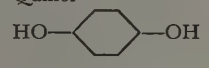
hole whose centre is much closer to the surrounding cagework atoms than the equilibrium van der Waals distances between unlinked atoms. In approaching such a position, the atom will be subjected to the forces of mutual repulsion that develop when any two atoms are sufficiently close. These forces, evident in the comparative incompressibility of molecular liquids and solids, increase greatly in their intensity as the interatomic distance diminishes below the equilibrium value, and, the cage being held together by strong forces, the enclosed atom will be forced back. There will always be some attraction due to van der Waals or other forces between the enclosed and enclosing components of such a molecular compound, and it may be of great importance in bringing the molecules into the correct positions for enclosure when the crystal is formed, but once the atom or molecule is enclosed it cannot escape merely by overcoming this attraction.

(2) The volatile component will be set free in processes which destroy the cage structure. Thus, argon is set free when the quinol-argon compound is heated to temperatures at which quinol molecules break their hydrogen bonds and volatilize. The gas is also liberated by dissolution of the compound in any solvent for quinol.

(3) Compound formation is restricted to particular pairs of molecules by geometrical rather than by chemical characteristics. Thus, the arrangement shown in figure 1 has six —OH groups of six different quinol molecules in the form of a hexagon, with the O—C bonds pointing alternately above and below the hexagons in such a manner that these bonds are at approximately the tetrahedral angle to the hydrogen bonds, as is commonly the case. If the —OH groups remote from these six are made geometrically equivalent to the first set, they in their turn form part of other hydrogen-bonded hexagons, and the result is the extended giant molecule which, with its identical interpenetrant twin, forms the enclosing structure of the molecular compounds. Substitution of the isomeric resorcinol, with the —OH groups in different relative positions in the molecule, is a drastic change geometrically incompatible with these requirements. This molecule therefore cannot replace quinol, although it is conceivable that it might form compounds of a similar character on a different geometrical plan.

Since the cavities are of predetermined form, apart from the minor variations, the only molecules capable of enclosure are those which have a size and shape that can fit into the available space, and which at the same time are large enough not to escape through the holes. With quinol, the methanol molecule is enclosed, but the ethanol molecule is too large and the water molecule too small. Argon is enclosed, but the helium atom, well known for its ability to penetrate small holes, does not give a similar compound.

(4) There is a limiting composition, determined by the ratio of the number of cage-forming molecules to the number of cavities. The second component may be present in quantity less than the permitted maximum because some of the cavities are unoccupied. It is found in the case of the quinol β-type compounds that, when the compound is obtained by simple crystallization from the second component, e.g. methanol or methyl cyanide used as solvent, almost all the cavities are occupied, and the ideal formula 3 quinol/M is attained. When it is necessary to use an indifferent solvent to get the two components together,

	Component A	*Component B*	*Composition of molecular compound*
I	Aromatic polynitro compounds such as *s*-trinitrobenzene (1)	Aromatic hydrocarbons and their derivatives, e.g. naphthalene or aniline	Frequently A.B., but other simple ratios are known.
II	4:4′ dinitrodiphenyl (2) 	4:4′ substituted diphenyls	A_n.B n increases as length of molecule B is increased. For B = 4:4′-diacetoxydiphenyl, $n = 5$; for others $n = 4$, $3\frac{1}{2}$, 3 according to molecular length.
II	Deoxycholic acid .. (3)	Fatty acids, normal paraffins, and some other substances	A_n.B. n = 1, 3, 4, 6, or 8, increasing as length of fatty acid molecule increases.
II	Urea .. .. .. (4)	Normal paraffins, carboxylic acids, alcohols, esters, etc.	A_n.B. n in general not integral and having values from 4 upwards, increasing with increase in length of molecule B.
III	Quinol (5) 	MeOH, MeCN	A_3.B
III	Quinol	H_2S, SO_2, HCl, HBr, HCN, CO_2, C_2H_2, A, Kr, Xe	Approximating to A_3B, but with less B than formula requires and with variable proportion of B.
III	Complex structure of composition $Ni(CN)_2.NH_3$ (6)	Benzene, thiophene, and a few similar molecules, but not the homologues	A.B

a considerable proportion of spaces may be left vacant. This is noticed for compounds such as those containing hydrogen sulphide, sulphur dioxide, and hydrogen bromide. Since the difficulty of getting a molecule into an already formed empty cavity is the same as that of getting it out of an occupied one, these vacant spaces, once formed, are preserved, and the frequency of their occurrence must depend on factors (such as concentration of the dissolved volatile component) which affect the chance of its molecules being in the position for enclosure at the instant when the cage is formed. Some of the compounds are therefore formed by crystallization of solutions of quinol in which the concentration of the dissolved gas is raised by pressure.

Knowledge of the nature of molecular compounds helps in the solution of some problems, and various possibilities of using it suggest themselves.

Sometimes a molecular compound has been mistaken for one of its components. Thus, the substance formerly called β-quinol, a supposedly polymorphic form of quinol obtained by crystallization from methanol, proves to be the methanol compound belonging to the clathrate series already mentioned. However, the hidden character of the methanol compound is such that this substance has survived a number of investigations of its properties up to the most recent times without detection of the masquerade. Unfamiliar molecular ratios, and a small proportion of one component, may add to the difficulty of detection. Elementary analysis could fail in particular cases when the components have similar compositions, and since the molecular compound decomposes on solution its reactions may appear to be entirely those of the component which it is thought to be. In particular, if the other constituent is the same as the solvent used the deception is complete.

More frequently, however, a substance, whose constitution does not seem to be otherwise in doubt, may give unexpected analytical figures which are due to the solvent combining in this way. Once the possibility is suspected the solution of the problem is not difficult.

There are possibilities for the use of such compounds in processes of purification, separation, identification, and quantitative estimation. Attempted purification of a substance by some methods becomes difficult owing to the continued presence of those impurities which have similar solubility, volatility, or other properties, and at this important stage a means of separation dependent on a different factor may be applied. Molecular size and shape may be so different that the separation may be made as complete as one based, at an earlier stage, on some profound chemical difference. The case of the urea-hydrocarbon compounds already mentioned illustrates different behaviour of straight-chain and branched isomers. In crystals containing long molecules in channels, the different members of a straight-chain series may not be separable, but in the clathrate types where closed cavities of fixed dimensions are occupied there is a highly selective action. This is illustrated by the formation by quinol of this kind of compound with methanol alone of the alcohols, since methanol is the only one with a molecule of a size to fit the available space.

In a somewhat similar manner the nickel cyanide/ammonia complex forms compounds with benzene and a few other substances, such as thiophene, furane, pyrrole, aniline, and phenol. The cage formation of the nickel cyanide/ammonia complex is perhaps not so complete as that of the quinol compounds, but it is extremely difficult to remove the benzene from the compound, and the action in combining with benzene has for years been regarded as so specific as to afford a means of quantitative gas analysis. Benzene may thus be separated from non-aromatic hydrocarbons and from its own homologues.

The reasons for the formation of these compounds, and the circumstances in which they are likely to occur, cannot be considered in this article, but some indication of their possible significance in other fields may be given. The association of two substances without the necessity of chemical combination in the ordinary senses may be common in nature. Loose compounds of the kind discussed may be of importance in biological systems. There is a clear illustration of specificity associated with the fitting together of two molecular components in some of these structures, which may serve as models for the much more complex molecular arrangements in living matter.

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Book reviews

CHEMOTHERAPEUTICS

Chemical Constitution and Biological Activity, *by W. A. Sexton, with a Foreword by A. R. Todd. Pp.* 434, *with* 42 *figures and* 58 *tables. E. and F. N. Spon Limited, London.* 1949. 55*s. net.*

The rapid increase in our knowledge of the chemistry of biological materials now permits a more fundamental approach to be made to the problems of chemotherapy. In this volume Dr Sexton brings together a wealth of information concerning the biological activity of chemical substances, and discusses in detail the relation between chemical constitution and biological response. The book is divided into two parts. The first five chapters contain synopses of the fundamental scientific principles involved, including a survey of proteins, enzymes, macromolecules of biological importance, the physical chemistry of bacterial growth, and so on. The remaining sixteen chapters give detailed accounts of the action of the many substances which have been used in chemotherapy, and chapters on insecticides and plant-growth regulators are also included. The story is a fascinating one for the general reader, who will be amazed at the amount of careful work which has already been done in this field, and the book with its tables, summaries, and references will be indispensable to the research worker. Many spectacular results have been achieved, including, for instance, the sulphonamide drugs, penicillin, Paludrine, and Antrycide, and within certain groups considerable correlation between structure and activity has been achieved. But the main impression given by Dr Sexton's balanced and comprehensive survey of these vitally important topics is of the need for yet more investigations, both biological and chemical, before a full understanding will be possible of the mechanisms by which chemotherapeutic materials exert their effects. E. L. HIRST

ORGANIC CHLORINE COMPOUNDS

The Preparation, Properties, Chemical Behaviour, and Identification of Organic Chlorine Compounds. Tables of Data on Selected Compounds of Order III. *By E. H. Huntress. Pp. xxv + 1443. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1948. 165*s. net.*

This volume deals in detail with some thirteen hundred compounds containing carbon and chlorine; carbon, oxygen, and chlorine; carbon, hydrogen, and chlorine; or carbon, hydrogen, oxygen, and chlorine. It differs notably from the earlier volume, published jointly with the late Professor S. P. Mulliken, in that, although the general method of classifying compounds is retained, the treatment is in no sense restricted to problems of identification but includes an account of preparative methods, physical properties, and general chemical behaviour. Over twenty thousand literature references are given, and, since a fair number of the compounds dealt with are relatively new, the book will in these cases serve as a supplement to Beilstein. References to patents are also given, and in this and other respects the work will be of special value to industrial users. The first chapter is devoted to a detailed explanation of the method of classification used, and formulae and name indexes, as well as an index based on chemical types, are provided. In a reference book of this sort much depends on accuracy, completeness, and systematic presentation. There is every indication that Professor Huntress has had these criteria constantly before him in bringing to so satisfactory a conclusion a formidable but most valuable task. H. J. EMELÉUS

ORGANIC REACTIONS

Organic Reactions, Vol. IV. *Edited by Roger Adams, W. E. Bachmann, A. H. Blatt, L. F. Fieser, J. R. Johnson, and H. R. Snyder. Pp. 428. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1948. 36*s. net.*

This, the latest issue of a well-known series of handbooks, proceeds on the lines laid down by its forerunners. The account of the Diels-Alder reaction, with its numerous variations, occupies over 170 pages, presenting the most extensive summary which has so far appeared. The discussion of this reaction refers to its mechanism, reversibility, stereochemical selectivity, side reactions, limitations, and abnormalities, including an interesting loss of sulphur from dinaphthylenethiophen. The light which this reaction has thrown upon the mechanism of polymerization is emphasized.

The preparation of amines from ammonia and an aldehyde or ketone with a reducing agent, including Raney nickel, is also described. The possible intermediate formation of a Schiff's base in the reaction as catalysed by nickel or metallic oxides is discussed, and also the formation of by-products, e.g. pyridine bases. The chapters on the analogues of benzoin contain a useful theoretical discussion on the formation of acyloins from esters or acid chlorides and sodium. In discussing the use of hydrazine for the reduction of carbonyl groups the Wolff and the Kishner reactions are distinguished, and are critically compared with the Clemmensen reaction. The catalytic reduction of acid chlorides and the formation of quinones by oxidation also receive considerable attention. The tables of information regarding compounds prepared by, or undergoing, these reactions occupy 40 per cent. of the book.

FREDERICK CHALLENGER

SYNTHETIC RUBBER

Modern Synthetic Rubber, *by H. Barron. 3rd edition. Pp. xx + 636. Chapman and Hall Limited, London.* 1949. 45*s. net.*

Nobody could deny that this is an attractive book, but it is impossible to decide whether the author intended it to be a semi-popular exposition or a serious textbook. In fact, it has fallen between the two extremes. The book is based on what the author describes as a 'simple system,' but the system is actually complex and unnecessary. To describe an artificial rubber as a synthetic rubber is much nearer the truth than to describe such hard plastics as polyvinyl chloride or polythene as 'synthetic elastics.' It is doubtful if any purpose is served by including plastics which can be made to a certain extent rubbery by plasticization in a book on synthetic rubbers. In the opinion of the reviewer a greater effort on the part of the author to master the contents of the C.I.O.S. and B.I.O.S. reports before attempting to summarize them would have been time more profitably spent. For example, under 'latex stripping' the author appears to have missed the barometer principle in the design of this important piece of equipment. The third edition is without question a great improvement on the earlier editions, but the fourth edition should be expedited to eliminate the still remaining errors, such as the statement that polythene is unaffected by ultra-violet light, that rubber is the *trans* isomer of polyisoprene, and so forth. W. J. S. NAUNTON

CARBOHYDRATE CHEMISTRY

An Introduction to the Chemistry of Carbohydrates, *by John Honeyman. Pp. 143, with line diagrams. Oxford University Press, London.* 1948. 15*s. net.*

Dr Honeyman has been successful in producing a readable textbook on carbohydrate chemistry. The subject has been developed in a logical manner; the treatment of the chemistry of the monosaccharides is good, and there is a useful section on cellulose derivatives in Chapter XI. One thought Chapter IX to be too short to be of real value, however, and that the important synthetic work of Burkhardt Helferich might have found a place in Chapter X. The formulation of inulin (p. 133) seems unfortunate, since the β-linkage is the most probable for this polysaccharide, and the statement that alginic acid is extracted from seaweed by sodium hydroxide should be corrected.

It must also be stated that the system used for references breaks down occasionally, for a student seeking the original papers on end-group assay under Haworth (1928) would experience difficulty in finding them, since the work was not carried out until 1932; in any case it is doubtful if many degree students will afford the time to search the abstracts as advised in the preface. Apart from such minor blemishes, the book must be warmly commended. E. G. V. PERCIVAL

ORGANIC SYNTHESES

Organic Syntheses (Volume 28). *Editor-in-Chief, H. R. Snyder. Pp. 121, with several line illustrations. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1949. 15*s. net.*

This volume of 'Organic Syntheses' contains detailed instructions for the preparation of a number of organic compounds. The instructions are considerably more precise than those which are usually given in original publications, where the preparations are often so condensed that the non-specialist has

difficulty in repeating them. The unsatisfactory descriptions of many preparations in chemical journals are, however, not always due to brevity; yields are frequently not recorded, temperature and duration of reaction are masked by such phrases as 'warmed for a few minutes,' or a reaction is stated to be carried out 'in the usual manner.' Experience has shown that the reactions described in 'Organic Syntheses' will proceed as described, and give the final product in the yield and of the purity claimed. There are many additional notes, references to original literature, and mention of alternative methods of preparation. A list of the thirty-seven preparations is given below:

2-Acetothienone (2-acetylthiophen), 2-acetylfluorene, 9-acetylphenanthrene, 2-allylcyclohexanone, *o*-aminobenzaldehyde, *p*-aminophenyl disulphide, benzoyl disulphide, 9-bromophenanthrene, 4-bromo-*o*-xylene, 3-carbethoxycoumarin, *p*-chloroacetylacetanilide, *m*-chlorophenylmethylcarbinol, *m*-chlorostyrene, 9-cyanophenanthrene, *trans*-1:2-cyclohexandiol, 4:7-dichloroquinoline, 2:5-dihydroxyacetophenone, di-*iso*valerylmethane, 3:4-dimethylaniline, 2:4-dimethylquinoline, 1:4-dinitronaphthalene, diphenylacetonitrile, ethyl azodicarboxylate, ethyl ethoxymethylenemalonate, fluorenone-2-carboxylic acid, hexamethylene chlorohydrin, hydroquinone diacetate, 2-hydroxycinchoninic acid, *dl-iso*propylideneglycerol, methyl-4-keto-7-methyloctanoate, 4-nitro-1-naphthylamine, *p*-nitrophenyl sulphide, phenanthrene-9-aldehyde, 1-phenyl-3-amino-5-pyrazolone, α-phenylthiourea, 2:4:7-trinitrofluorenone, vinyl chloroacetate.

The subject index covers the contents of volumes 20–28. W. BAKER

GENII OF THE CRUCIBLE

Crucibles: the Story of Chemistry from Ancient Alchemy to Nuclear Fission, *by Bernard Jaffe. Second English edition. Pp. xiv + 480. Hutchinson's Scientific and Technical Publications, London.* 1949. 18*s. net.*

The great advances in chemistry that have occurred since the first English edition of this book was published in 1931 have led to a drastic revision of the original last chapter and to the inclusion of three new chapters dealing with 'Ernest Orlando Lawrence,' 'The men who harnessed nuclear fission,' and 'Nuclear energy tomorrow.' In the complexities of sub-atomic chemistry, teamwork has played so great a part that in his closing chapters the author has had to abandon his device of dramatizing a specific figure as typical of a particular scientific era. The new part of the book paints a vivid picture of the marvels of the sub-atomic world, and of the unbounded energy and ingenuity of man in a work that may lead to his own destruction if he continues to develop cleverness at the expense of morality. Starting with alchemy—the treatment of which is superficial—here is a story unwinding at an increasing tempo and told with great zest. The last part of the book is easily the best. It gives a very readable account of the dominating part played in the more recent stages of sub-atomic chemistry by American physical scientists endowed with prodigious experimental resources. Although the second edition of this lively and human treatment contains some regrettable inaccuracies, it depicts the march of chemistry with a glowing enthusiasm worthy of the title. JOHN READ

THE SERVICE OF SCIENCE

Science, Servant of Man. A Layman's Primer for the Age of Science, *by I. Bernard Cohen. Sigma Press, London.* 1949. 15*s. net.*

This is a book of some importance, written for the layman but affording food for thought to the scientist. Its purpose is to study the conditions under which scientific discoveries of practical value are made, and this intricate problem is handled clearly and with good sense. The various types of scientific discovery are examined, and it is clearly shown that no single description can cover all or even a majority. Some are happy accidents exploited by a curious and receptive mind, others are by-products of researches conducted for quite different ends, others again are the results of planned researches, others of the utilization of principles discovered many years before, at a time when no use for them could be found. A large part of the book consists of exemplary description of various researches, such as those that led to penicillin, synthetic rubber and nylon, hybrid corn, and the like: these seem to the reviewer to be well done and free from error. In surveying the method by which the greatest quantum of usefulness can be obtained from science, Mr Cohen comes down firmly against the enthusiasts for planning, quoting Dr Oliver E. Buckley, who says: 'All successful industrial directors have learned by experience that one thing a "director of research" must never do is to direct research. . . .'

F. SHERWOOD TAYLOR

FARADAY AND INDUCTION

Faraday's Discovery of Electro-magnetic Induction, *by Thomas Martin. Pp.* 160, *with half-tone and line illustrations. Edward Arnold and Co., London.* 1949. 9*s. net.*

Mr Martin is already well known as the patient and devoted editor of Faraday's diary, and little need therefore be said about the value of his latest book, which describes Faraday's work leading to the discovery of electromagnetic induction in all its fascinating detail, with facsimile reproductions of more than fifty of Faraday's freehand sketches.

Mr Martin emphasizes the importance of Faraday's earlier experiments in this field in 1821, and his close study of all that was done by others from 1821 to 1831—a period during which his attention was largely directed to other problems—until he then returned to continue his electrical researches without further interruption. Then came the rapid discoveries, from the ring experiment of 29th August to the production on 17th October of an induced current by the movement of a magnet in a coil of copper wire, and so on to the production of continuous currents by induction, of induced currents by means of the earth's magnetism, and of the 'magneto-electric spark.'

This excellent presentation of the sequence of Faraday's thoughts and experiments does much to reveal the mind and genius of that great master.

D. MCKIE

METAL PHYSICS

Progress in Metal Physics, *edited by Bruce Chalmers. Pp.* 401. *Butterworth's Scientific Publications, London.* 1949. 45*s. net.*

The purpose of this volume is explained by the editor as being 'to present authoritative reviews of the present state of knowledge in specialized aspects of the field that includes both physical metallurgy and metal physics.' There are seven reviews in this first series, and it is intended to keep the work up to date by publishing subsequent articles confined to more recent progress. As the articles in the present volume are the first of the series they also include the necessary historical background.

Metal physics is a relatively new subject, the importance of which is being increasingly recognized. To the knowledge of the structure of metals as shown by the microscope, and the vast body of data about their physical properties, have now been added the knowledge of atomic pattern, crystallite size and strain obtained by X-rays, and the information about structure on a very minute scale revealed by the electron microscope. We are in a much stronger position to attempt to explain the physical properties of metals in terms of their atomic arrangement.

It is no criticism of the authors of the articles to say that the volume gives a deep impression of bewildering complexity. There is an extraordinary contrast between the extreme simplicity of the perfect crystal of a pure metal, of whose nature the atomic physicists have given us a reasonably complete explanation, and the complexity of behaviour when the ideal symmetry is destroyed. When alloys and solid solutions are considered, the complexity is almost infinitely increased. We still await the genius who can order and arrange these facts, and give us a clue to the maze by unifying and simplifying theory. The study of the theory of alloys is the most satisfactory, or perhaps one should say the least unsatisfactory, in this respect. Here one does begin to see bits of the jigsaw puzzle falling into place; the knowledge of atomic arrangement allied to the quantum theory has for the first time put metal chemistry on a hopeful basis. In the sections on the theory of dislocations and crystal boundaries, and their effects on slip and creep, hardening and fracture, one is still groping in the dark. Advance depends upon a much deeper understanding of the number and arrangement of the dislocations, the units in terms of which we seek to define the departure from the perfect crystalline form, and by whose movements we seek to explain the flow of the metal. Until more is known about their physical nature, such mathematical theory as has been developed is really little more than a conventional fig-leaf to cover the utter nakedness of intuitive guesses. The technologist still has to wait patiently for the advance of pure science which one day will give him a lead. The section on the hardening response of steels is more technical than the other sections, as is natural in view of the complexity of the phenomena. In the section on diffusion it is possible to use well-developed mathematical techniques, though here again the understanding of the fundamental physical phenomena is very incomplete.

We must be grateful to the authors for the patience and skill with which they have addressed themselves to the task of summarizing the subject of metal physics in its present state. Its importance in industry is very great indeed, and we must encourage research so that Britain may be in the forefront of development. In this review the researcher can find a reference to all the significant work which has been carried out in recent years, scattered widely over many journals, and it will be of the very greatest assistance to him.

W. L. BRAGG

HISTORY OF SUGAR

The History of Sugar, *by Noel Deerr. Vol.* 1, 1949, *pp.* 258, *with* 20 *plates,* 6 *figures, and* 8 *maps in text; Vol.* 2, 1950, *pp.* 259–636, *with* 11 *plates and* 42 *figures in the text. Chapman and Hall Limited, London.* 50*s. and* 55*s. net.*

This is a thorough historical survey of the sugar industry in its many aspects, and new and valuable materials, and some delightful illustrations, have been brought to light by the author's painstaking researches in libraries, domestic histories, long-buried journals, and other little-known sources. Although he begins by introducing us to prehistoric man in quest of honey, and to the many sources of sugar in nature, his main theme in volume 1 is the production of sugar from cane. The treatment is both detailed and comprehensive, and the subject-matter is so arranged that one can immediately gain a clear and adequate impression of the historical development of the industry whether in China, the Mediterranean, or the French West Indies.

Fourteen chapters in all are devoted to the establishment and development of the industry in different regions of the world. And what good reading this makes, not only because of the author's evident though restrained delight in the scholarship which has gone to the making of this work, but because, in a sense, and in no small degree, sugar and history are synonymous. That this is so becomes still more evident in Volume 2, where although, as the author tells us, his intentions were otherwise, he has been impelled to deal at length with the question of slavery. For, as the facts now before us show with convincing clarity, the rise of the sugar industry and the extension of industrial slavery were correlated to a remarkable extent, not only during the more recent centuries with which most people are somewhat familiar, but through the ages. To this harrowing but fascinating topic three chapters are devoted. For those who yearn for a glimpse of the old-time planter's life under tropic skies there is a most interesting account of 'The Plantation and the Planter.' Three chapters are devoted to the emancipation of slaves and consequential developments, and one to the 'blackbirding' traffic which persisted in some regions almost into our own times. Other chapters deal with the trade in sugar, sugar duties, refining, prices, etc., considerable space being devoted to the sugar beet industry and to minor sources of sugar; the more technical reader will find a condensed but valuable illustrated chapter on the effects of invention and research on the development of the industry. The author is to be congratulated on the sustained scholarship which characterizes this survey of one of the world's most vital crops, and the publishers on these handsome volumes.

C. W. WARDLAW

BRITISH SCIENTIFIC JOURNALS

A List of British Scientific Publications Reporting Original Work or Critical Reviews. *Pp.* 95. *Published for the Royal Society by the Cambridge University Press, London.* 1950. 2*s.* 6*d. net.*

At the Royal Society Scientific Information Conference held in 1946 many delegates felt that it would be of great value to have a list of the scientific journals published in the United Kingdom which include a substantial proportion of original work or critical reviews. This publication is the result of these recommendations. It does not claim to be comprehensive, but it lists about 220 journals, giving for each a short description of its contents and details of its frequency of publication, its current volume number, approximate size, whether summaries of papers are given, whether advertisements are accepted, where and how directions to authors can be obtained, its price, the editorial address, and the address of the publishing organization.

The book is well indexed, and any specific journal or the journals devoted to any one subject can be found without difficulty. It is to be hoped that the book will be kept in print and that in preparing future editions the list will be even more comprehensive.

Some books received

(*Note:* Mention of a book on this page does not preclude subsequent review.)

AGRICULTURE

Soils—Their Physics and Chemistry, *by A. W. Puri. Pp.* 550, *with several line diagrams. Reinhold Publishing Company, New York; Chapman and Hall Limited, London.* 1949. 56*s. net.*

ASTRONOMY

Cosmical Electro-Dynamics, *by H. Alfvén. Pp.* 237, *with various line diagrams. Oxford University Press, London.* 1950. 25*s. net.*

BIOLOGY

Biology, *by P. D. F. Murray. Pp.* 600, *with numerous line drawings and half-tones. Macmillan and Company Limited, London.* 1950. 25*s. net.*

The Biology of Melanomas. *Editor: Roy Waldo Miner; Consulting Editor: Myron Gordon. Pp.* 466, *with half-tone and line illustrations. New York Academy of Sciences.* 1948. $5 *net.*

Evolution, *by Chapman Pincher. Pp.* 199, *with various line diagrams. Herbert Jenkins Limited, London.* 1950. 7*s.* 6*d. net.*

BOTANY

Adaptation and Origin in the Plant World, *by Frederic E. Clements, Emmett V. Martin, and Frances L. Long. Pp.* 332, *with numerous half-tones and line diagrams. Chronica Botanica Company, Waltham, Mass., U.S.A.*

Water in the Physiology of Plants, *by A. S. Crafts, H. B. Currier, and C. R. Stocking. Pp.* 240, *with several line diagrams. Chronica Botanica Company, Waltham, Mass., U.S.A.; Wm. Dawson and Sons Limited, London.* 1949. $6 *net.*

CARTOGRAPHY

Aerial Mapping and Photogrammetry, *by Lyle G. Trorey. Pp.* 178, *with numerous half-tones and line diagrams. Cambridge University Press, London.* 1950. 25*s. net.*

CHEMISTRY

Advanced Chemical Calculations, *by S. J. Smith. Pp.* 454. *Macmillan and Company Limited, London.* 1950. 17*s. net.*

Advanced Organic Chemistry (*second edition*), *by G. E. Wheland. Pp.* 799. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1949. 64*s. net.*

Boron Trifluoride and its Derivatives, *by Harold Simmons Booth and Donald Ray Martin. Pp.* 315, *with several line diagrams. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1949. 40*s. net.*

The Chemical Elements and their Compounds, *by N. V. Sidgwick. Two volumes, pp.* 1703. *Oxford University Press, London.* 1950. 70*s. net.*

Organic Chemistry, *by Paul Karrer. Fourth English edition. Pp.* 983. *Elsevier Publishing Company Limited, Amsterdam; Cleaver-Hume Press, London.* 1950. 57*s.* 6*d. net.*

Organic Reactions, *Vol. V. Editor-in-Chief: Roger Adams. Pp.* 446. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1949. 48*s. net.*

Solvents, *by R. H. Durrans. Pp.* 242. *Chapman and Hall Limited, London.* 1950. 21*s. net.*

Structural Carbohydrate Chemistry, *by E. G. V. Percival. Pp.* 246, *with several line diagrams. Frederick Muller Limited, London.* 1950. 25*s. net.*

ENGINEERING

Aerials for Centimetre Wave-Lengths, *by D. W. Fry and F. K. Goward. Pp.* 172, *with numerous line diagrams. Cambridge University Press, London.* 1950. 18*s. net.*

The Mathematical Theory of Communication, *by C. E. Shannon and W. Weaver. Pp.* 117. *University of Illinois Press, U.S.A.* 1949. $2.50 *net.*

GENERAL SCIENCE

The Growth of Scientific Ideas, *by W. P. D. Wightman. Pp.* 495, *with various half-tone and line illustrations. Oliver and Boyd Limited, Edinburgh.* 1950. 25*s. net.*

Science and Literary Criticism, *by Herbert Dingle. Pp.* 184. *Thomas Nelson and Sons Limited, Edinburgh.* 1949. 7*s.* 6*d. net.*

Science News No. 15, *edited by J. L. Crammer. Pp.* 192, *with half-tone and coloured illustrations. Penguin Books, London.* 1950. 1*s.* 6*d. net.*

INDUSTRY

Co-operative Industrial Research, *by Ronald S. Edwards. Pp.* 285. *Pitman and Sons Limited, London.* 1950. 20*s. net.*

Freeze-Drying—Drying by Sublimation, *by Earl W. Flosdorf. Pp.* 280, *with numerous half-tone and line illustrations. Reinhold Publishing Company, New York; Chapman and Hall Limited, London.* 1949. 40*s. net.*

MEDICINE

Human Ability, *by C. Spearman and Ll. Wynn Jones. Pp.* 198. *Macmillan and Company Limited, London.* 1950. 16*s. net.*

Recent Advances in the Physiology of Vision, *by Hamilton Hartridge. Pp.* 401, *with numerous line diagrams. J. and A. Churchill Limited, London.* 1950. 25*s. net.*

Temperature and Human Life, *by C.-E. A. Winslow and L. P. Herrington. Pp.* 272, *with various line diagrams. Oxford University Press, London.* 1949. 28*s. net.*

OCEANOGRAPHY

The Sea and its Mysteries, *by John S. Colman. Pp.* 285, *with various line drawings and half-tone illustrations. G. Bell and Sons Limited, London.* 1950. 12*s.* 6*d. net.*

PHYSICS

Counting Tubes, *by S. C. Curran and J. D. Craggs. Pp.* 238, *with several line diagrams. Butterworth's Scientific Publications Limited, London.* 1949. 35*s. net.*

Heat Transfer, *Vol.* 1, *by Max Jakob. Pp.* 758, *with several line diagrams. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1949. 96*s. net.*

Phenomena, Atoms and Molecules, *by Irving Langmuir. Pp.* 436, *with several line diagrams. Philosophical Library, New York.* 1950. $10 *net.*

Physical Properties of Glass, *by J. E. Stanworth. Pp.* 224, *with line diagrams. Oxford University Press, London.* 1950. 21*s. net.*

The Physics of High Pressure, *by P. W. Bridgman. Pp.* 445, *with various half-tones and illustrations. G. Bell and Sons Limited, London.* 1950. 35*s. net.*

Radiative Transfer, *by S. Chandrasekhar. Pp.* 393, *with several line diagrams. Oxford University Press, London.* 1950. 35*s. net.*

ZOOLOGY

Practical Invertebrate Anatomy, *by W. S. Bullough. Pp.* 463, *with line diagrams. Macmillan and Company Limited, London.* 1950. 28*s. net.*

Traité de Zoologie, *Vol. XV.* Oiseaux. *Publié sous la direction de Pierre-P. Grassé. Pp.* 1164, *with many line drawings and half-tone illustrations. Masson et Cie., Paris.* 1950. 6000 *fr. net.*

Notes on contributors

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